FINAL REPORT OF SPECIFIC PURPOSE LIDAR SURVEY

LiDAR, Breaklines and Contours for

Clay and Putnam Counties, Florida

State of Florida
Division of Emergency Management
Contract 07-HS-34-14-00-22-469
and Add-On Agreement with
Clay County, Florida

October 30, 2009

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Final Report of Specific Purpose LiDAR Survey, including

LiDAR-Generated Breaklines and Contours for Clay and Putnam Counties, Florida

FDEM Contract 07-HS-34-14-00-22-469 with:

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Table of Contents

Report of Specific Purpose LiDAR Survey, LiDAR-Generated Breaklines and Contours Clay and Putnam Counties, Florida

Type of Survey: Specific Purpose Survey

This report pertains to a Specific Purpose LiDAR Survey of Clay and Putnam Counties, Florida, referred to herein as Clay-Putnam. The LiDAR aerial acquisition was conducted by Terrapoint USA between August 18, 2007 and September 4, 2007, and the breaklines and contours were subsequently generated by Dewberry. The PDS team is under contract 07-HS-34-14-00-22-469 with the Florida Division of Emergency Management (FDEM) and provided LiDAR and derived products as an add-on agreement with Clay County at the same rates as negotiated for the FDEM contract and utilizing the same Baseline Specifications from FDEM.

The LiDAR dataset of Clay-Putnam Counties was acquired by Terrapoint USA and processed to a bare-earth digital terrain model (DTM) in accordance with FDEM Baseline Specifications. Detailed breaklines and contours were also produced by the PDS team. Each tile covers an area of 5000 ft by 5000 ft. The map at Appendix A displays the 464 tiles of Clay-Putnam Counties for which LiDAR DTMs and LiDAR-derived breaklines and contours were produced by the PDS team.

The FDEM Baseline Specifications require a maximum LiDAR post spacing of 4 feet, i.e., an average point density of less than 1 point per square meter. However, the PDS team required a much higher point density of its subcontractors in order to increase the probability of penetrating dense foliage; with nominal post spacing of 0.7 meters per flight line and 50% sidelap between flight lines, the average point density is 4 points per square meter. With higher point density there is a greater probability of penetrating dense vegetation and minimizing areas defined as "low confidence areas."

The PDS Team

PDS is a Joint Venture consisting of PBS&J, Dewberry, and URS Corp:

- PBS&J provided local client liaison in Tallahassee. PBS&J was also responsible for the overall ground survey effort including management of field survey subcontractors -- Allen Nobles & Associates, Inc. (ANA) and Diversified Design & Drafting Services, Inc. (3DS) -- which performed the QA/QC checkpoint surveys used for independent accuracy testing by Dewberry and URS. Mr. Glenn Bryan, PSM, of PBS&J, and Mr. Brett Wood, PSM, of 3DS, were the technical leads for the QA/QC surveys.

- Dewberry was responsible for the overall Work Plan and aerial survey effort, including management of orthophoto and LiDAR subcontractors that performed the data acquisition and post-processing and produced the major deliverables. A staff of QA/QC specialists at Dewberry's Fairfax (VA) office performed accuracy testing and quality assessments of the digital orthophotos, breaklines and contours. Dewberry served as the single point of contact with FDEM. Dr. David Maune, PSM, was Dewberry's technical lead for the digital orthophoto and LiDAR surveys and derived products.

- URS Corp. was responsible for data management and information management. URS developed the GeoCue Distributed Production Management System (DPMS), managed and tracked the flow of data, performed independent accuracy testing and quality assessments of FDEM's new LiDAR data acquired in 2007, tracked and reported the status of individual tiles during production, and produced all final deliverables for FDEM. Mr. Robert Ryan, CP, of URS, was the technical lead for this effort.

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Survey Area

The project area for this report encompasses 464 tiles, approximately 416 square miles, within Clay and Putnam counties.

Map Reference

There are no hardcopy map sheets for this project. The map at Appendix A provides graphical reference to the 5000-ft x 5000-ft tiles covered by this report.

Summary of FDEM Baseline Specifications

All new data produced for the referenced contracts are required to satisfy the Florida Baseline Specifications included as appendices to PDS's Task Order C from FDEM, dated August 15, 2007, and Task Order D from FDEM, dated December 14, 2007. The tiling scheme, shown at Appendix A, is based on the Florida State Plane Coordinate System, East Zone.

The Florida Baseline Specifications required the LiDAR data to be collected using an approved sensor with a maximum field of view (FOV) of 20˚ on either side of nadir, with GPS baseline distances limited to 20 miles, with maximum post spacing of 4 feet in unobscured areas for random point data, and with vertical root mean square error ($RMSE_z$) $\leq$ 0.30 ft and Fundamental Vertical Accuracy (FVA) $\leq$ 0.60 ft at the 95% confidence level in open terrain (bare-earth and low grass); this accuracy is equivalent to 1 ft contours in open terrain when tested in accordance with the National Map Accuracy Standard (NMAS). In other land cover categories (brush lands and low trees, forested areas fully covered by trees, and urban areas), the Florida Baseline Specifications required the LiDAR data's $RMSE_z$ to be $\leq$ 0.61 ft with Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) $\leq$ 1.19 ft at the 95% confidence level; this accuracy is equivalent to 2 ft contours when tested in accordance with the NMAS. *Low confidence areas*, originally called *obscured vegetated areas*, are defined for areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

The Florida Baseline Specifications also require the horizontal accuracy to meet or exceed 3.8 feet at the 95% confidence level, using $RMSE_r$ x 1.7308. This means that the horizontal (radial) RMSE ($RMSE_r$)

must meet or exceed 2.20 ft. This is the horizontal accuracy required of maps compiled at a scale of 1:1,200 (1" = 100') in accordance with the traditional National Map Accuracy Standard.

To meet and exceed these specifications, the PDS team established the following more-rigorous specifications for its LiDAR subcontractors:

- Instead of a 20˚ FOV on either side of nadir, the PDS team limited the FOV to 18˚
- Instead of GPS baselines ≤ 20 miles, the PDS team limited baseline lengths to ≤ 20 km, except in one small isolated area where the baseline length was approximately 23 km (14 miles).
- Instead of 4 foot post spacing which yields an average of 0.67 points per m^2, the PDS team chose 0.7 m point spacing and 50% sidelap that yields an average of 4 points per m^2. Thus, the PDS team's average point density is nearly 6 times higher than required by FDEM, greatly increasing the probability of LiDAR points penetrating through dense vegetation so as to minimize areas defined as *low confidence areas*. The PDS team defines *low confidence areas* as vegetated areas of ½ acre or larger that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. Such areas indicate where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

The first deliverable is LiDAR mass points, delivered to LAS 1.1 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, includes LiDAR points in overlapping flight lines
- Class 9 = Water, includes LiDAR points in overlapping flight lines[1]
- Class 12 = Overlap, including areas of overlapping flight lines which have been deliberately removed from Class 1 because of their reduced accuracy.

Per FDEM's Baseline Specifications, for each 500 square mile area a total of 120 "blind" QA/QC checkpoints were surveyed, totally unknown to (i.e., "blind" from) the LiDAR subcontractor. Each set of 120 QA/QC checkpoints had the goal to include 30 checkpoints in each of the following four land cover categories:

- Category 1 = bare-earth and low grass
- Category 2 = brush lands and low trees
- Category 3 = forested areas fully covered by trees
- Category 4 = urban areas

The following vertical accuracy guidelines were specified by the Florida Baseline Specifications:

- In category 1, the $RMSE_z$ must be ≤ 0.30 ft ($Accuracy_z$ ≤ 0.60 ft at the 95% confidence level); $Accuracy_z$ in Category 1 refers to Fundamental Vertical Accuracy (FVA) which defines how

[1] Infrared radiation from LiDAR is partially absorbed by water, and all elevations in LAS Class 9 should be recognized as unreliable and treated accordingly.

accurate the elevation data are when not complicated by asphalt or vegetation that may cause elevations to be either lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 1 ft contours in non-vegetated terrain.

- In category 2, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 2 refers to Supplemental Vertical Accuracy (SVA) in brush lands and low trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In category 3, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 3 refers to Supplemental Vertical Accuracy (SVA) in forested areas fully covered by trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to be higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In category 4, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 4 refers to Supplemental Vertical Accuracy (SVA) in urban areas typically paved with asphalt and defines how accurate the elevation data are when complicated by asphalt that frequently causes elevations to be lower than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In all land cover categories combined, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in all categories combined refers to Consolidated Vertical Accuracy (CVA).
- The terms FVA, SVA and CVA are explained in Chapter 3, *Accuracy Standards & Guidelines*, of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published by the American Society for Photogrammetry and Remote Sensing (ASPRS), January, 2007.

A second major deliverable consists of nine types of breaklines, produced in accordance with the PDS team's Data Dictionary at Appendix C:

1. Coastal shoreline features
2. Single-line hydrographic features
3. Dual-line hydrographic features
4. Closed water body features
5. Road edge-of-pavement features
6. Bridge and overpass features
7. Soft breakline features
8. Island features
9. Low confidence areas

Another major deliverable includes both one-foot and two-foot contours, produced from the mass points and breaklines, certified to meet or exceed NSSDA standards for one-foot contours. Two-foot contours within obscured vegetated areas are not required to meet NSSDA standards. These contours were also produced in accordance with the PDS team's Data Dictionary at Appendix C.

Table 1 is included below for ease in understanding the accuracy requirements when comparing the traditional National Map Accuracy Standard (NMAS) and the newer National Standard for Spatial Data Accuracy (NSSDA). This table is extracted from Table 13.2 of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in January, 2007 by ASPRS. The traditional NMAS uses Vertical Map Accuracy Standard (VMAS) to define vertical accuracy at the 90% confidence level, whereas the NSSDA uses $Accuracy_z$ to define vertical accuracy at the 95% confidence level. Both the VMAS and $Accuracy_z$ are computed with different multipliers for the very same $RMSE_z$ value which represents vertical accuracy at the 68% confidence level for each equivalent contour interval specified. The term $Accuracy_z$ (vertical accuracy at the 95% confidence level) is comparable to the terms described below as Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) which also define vertical accuracy at the 95% confidence level. In open (non-vegetated) terrain, $Accuracy_z$ is exactly the same as FVA (both computed as $RMSE_z$ x 1.9600) because there is no logical justification for elevation errors to depart from a normal error distribution. In vegetated areas, vertical accuracy at the 95% confidence level ($Accuracy_z$) can also be computed as $RMSE_z$ x 1.9600; however, because vertical errors do not always have a normal error distribution in vegetated terrain, alternative guidelines from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) allow the 95^{th} percentile method to be used (as with the CVA and SVA) to report the vertical accuracy at the 95% confidence level in land cover categories other than open terrain.

Table 1. Comparison of NMAS/NSSDA Vertical Accuracy

NMAS Equivalent Contour Interval	**NMAS** VMAS (90 percent confidence level)	**NSSDA** $RMSE_z$ (68 percent confidence level)	**NSSDA** $Accuracy_z$, (95 percent confidence level)
1 ft	0.5 ft	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm
2 ft	1.0 ft	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm

The next major deliverable includes metadata compliant with the Federal Geographic Data Committee's (FGDC) Content Standard for Spatial Metadata in an ArcCatalog-compatible XML format. Copies of all survey reports, including this Report of Specific Purpose LiDAR Survey, must be delivered in PDF format as attachments to the metadata.

The last major deliverable includes the Vertical Accuracy Report of Clay-Putnam Counties, based on independent comparison of the LiDAR data with the QA/QC checkpoints, surveyed and tested in accordance with guidelines of the National Standard for Spatial Data Accuracy (NSSDA), American Society for Photogrammetry and Remote Sensing (ASPRS), Federal Emergency Management Agency (FEMA), and National Digital Elevation Program (NDEP), and using the QA/QC checkpoints surveyed by PBS&J and listed at Appendix E.

Datums and Coordinates: North American Datum of 1983 (NAD 83)/HARN for horizontal coordinates and North American Vertical Datum of 1988 (NAVD 88) for vertical coordinates. All coordinates are Florida State Plane Coordinate System (SPCS) in U.S. Survey Feet. Clay and Putnam Counties are both in the Florida SPCS East Zone 0901.

Appendix I to this report provides the Geodatabase structure for all digital vector deliverables in Clay-Putnam Counties.

Acronyms and Definitions

3DS	Diversified Design & Drafting Services, Inc.
$Accuracy_r$	Horizontal (radial) accuracy at the 95% confidence level, defined by the NSSDA
$Accuracy_z$	Vertical accuracy at the 95% confidence level, defined by the NSSDA
ANA	Allen Nobles & Associates, Inc.
ASFPM	Association of State Floodplain Managers
ASPRS	American Society for Photogrammetry and Remote Sensing
CFM	Certified Floodplain Manager (ASFPM)
CMAS	Circular Map Accuracy Standard, defined by the NMAS
CP	Certified Photogrammetrist (ASPRS)
CVA	Consolidated Vertical Accuracy, defined by the NDEP and ASPRS
DEM	Digital Elevation Model (gridded DTM)
DTM	Digital Terrain Model (mass points and breaklines to map the bare earth terrain)
DSM	Digital Surface Model (top reflective surface, includes treetops and rooftops)
FDEM	Florida Division of Emergency Management
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FOV	Field of View
FVA	Fundamental Vertical Accuracy, defined by the NDEP and ASPRS
GS	Geodetic Surveyor
LAS	LiDAR data format as defined by ASPRS
LiDAR	Light Detection and Ranging
MHHW	Mean Higher High Water
MHW	Mean High Water, defines official shoreline in Florida
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NMAS	National Map Accuracy Standard
NOAA	National Oceanic and Atmospheric Administration
NSSDA	National Standard for Spatial Data Accuracy
NSRS	National Spatial Reference System
NWFWMD	Northwest Florida Water Management District
PDS	Program & Data Solutions, joint venture between PBS&J, Dewberry and URS Corp
PS	Photogrammetric Surveyor
PSM	Professional Surveyor and Mapper (Florida)
QA/QC	Quality Assurance/Quality Control
$RMSE_h$	Vertical Root Mean Square Error (RMSE) of ellipsoid heights
$RMSE_r$	Horizontal (radial) Root Mean Square Error (RMSE) computed from $RMSE_x$ and $RMSE_y$
$RMSE_z$	Vertical Root Mean Square Error (RMSE) of orthometric heights
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SRWMD	Suwannee River Water Management District
SVA	Supplemental Vertical Accuracy, defined by the NDEP and ASPRS
TIN	Triangulated Irregular Network
VMAS	Vertical Map Accuracy Standard, defined by the NMAS

Ground Surveys and Dates

The GPS ground checkpoint surveys were executed by PBS&J personnel beginning January 29, 2008 and were completed on February 4, 2008.

The QA/QC checkpoints used for this county are listed at Appendix E.

LiDAR Aerial Survey Areas and Dates

Terrapoint USA collected the LiDAR data for Clay-Putnam Counties between August 18 and September 4, 2007.

LiDAR Processing Methodology

A LiDAR processing report from Terrapoint USA is included at Appendix D.

LiDAR Vertical Accuracy Testing

URS performed the LiDAR vertical accuracy assessment for Clay-Putnam Counties, consistent with *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, May 24, 2004, and Section 1.5 of the *Guidelines for Digital Elevation Data*, published by the National Digital Elevation Program (NDEP), May 10, 2004. These guidelines call for the mandatory determination of Fundamental Vertical Accuracy (FVA) and Consolidated Vertical Accuracy (CVA), and the optional determination of Supplemental Vertical Accuracy (SVA).

The LiDAR dataset of Clay-Putnam Counties passed the accuracy testing by URS as documented at Appendices E and F.

Fundamental Vertical Accuracy (FVA) is determined with QA/QC checkpoints located only in open terrain (grass, dirt, sand, and rocks) where there is a high probability that the LiDAR sensor detected the bare-earth ground surface, and where errors are expected to follow a normal error distribution. With a normal error distribution, the FVA at the 95 percent confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. The FVA is the same as $Accuracy_z$ at the 95% confidence level (for open terrain), as specified in Appendix 3-A of the *National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998, see http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3. For FDEM, the FVA standard is .60 feet at the 95% confidence level, corresponding to an $RMSE_z$ of 0.30 feet or 9.25 cm, the accuracy expected from 1-foot contours. ***In Clay-Putnam Counties, the $RMSE_z$ in open terrain equaled 0.28 ft compared with the 0.30 ft specification of FDEM; and the FVA computed using $RMSE_z$ x 1.9600 was equal to 0.55 ft compared with the 0.60 ft specification of FDEM.***

Consolidated Vertical Accuracy (CVA) is determined with all checkpoints, representing open terrain and all other land cover categories combined. If errors follow a normal error distribution, the CVA can be computed by multiplying the consolidated $RMSE_z$ by 1.9600. However, because bare-earth elevation errors often vary based on the height and density of vegetation, a normal error distribution cannot be assumed, and $RMSE_z$ cannot necessarily be used to calculate the 95 percent confidence level. Instead, a nonparametric testing method, based on the 95^{th} percentile, may be used to determine CVA at the 95 percent confidence level. NDEP guidelines state that errors larger than the 95th percentile should be documented in the quality control report and project metadata. For FDEM, the CVA specification for all classes combined should be less than or equal to 1.19 feet; this same CVA specification was used by NOAA. ***In Clay-Putnam Counties, the CVA computed using $RMSE_z$ x 1.9600 was equal to 0.90 ft, compared with the 1.19 ft specification of FDEM; and the CVA computed using the 95th percentile was equal to 0.87 ft compared with the 1.19 ft specification. The Clay-Putnam Counties dataset passed the CVA standard.***

Supplemental Vertical Accuracy (SVA) is determined separately for each individual land cover category, recognizing that the LiDAR sensor and post-processing may not have mapped the bare-earth ground surface, and that errors may not follow a normal error distribution. SVA specifications are "target" values and not mandatory, recognizing that larger errors in some categories are offset by smaller errors in other land cover categories, so long as the overall mandatory CVA specification is satisfied. For each land cover category, the SVA at the 95 percent confidence level equals the 95th percentile error for all checkpoints in that particular land cover category. For FDEM's specification, the SVA target is 1.19 feet for each category; this same SVA target specification was used by NOAA**.** ***In Clay-Putnam Counties, the SVA tested as 0.52 ft in open terrain, bare earth and low grass; 1.01 ft in brush lands and low trees; 0.85 ft in forested areas; and 0.88 ft in urban, built-up areas, passing the FDEM SVA baseline target specification of 1.19 ft in all land cover categories.***

The LiDAR Vertical Accuracy Report for Clay-Putnam Counties is at Appendix F.

LiDAR Horizontal Accuracy Testing

The LiDAR data was compiled to meet 3.8 feet horizontal accuracy at the 95% confidence level.

Whereas FDEM baseline specifications call for horizontal accuracy testing, traditional horizontal accuracy testing of LiDAR data is not cost effective for the following reasons:

- Paragraphs 3.2.2 and 3.2.3 of the National Standard for Spatial Data Accuracy (NSSDA) states: "Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy … when a dataset, e.g., a gridded digital elevation dataset or elevation contour dataset does not contain well-defined points, label for vertical accuracy only." Similarly, in Appendix 3-C of the NSSDA, paragraph 1 explains well-defined points as follows: "A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points."
- Paragraph 1.5.3.4 of the *Guidelines for Digital Elevation Data*, published in 2004 by the National Digital Elevation Program (NDEP), states: "The NDEP does not require independent testing of horizontal accuracy for elevation products. When the lack of distinct surface features makes horizontal accuracy testing of mass points, TINs, or DEMs difficult or impossible, the data producer should specify horizontal accuracy using the following statement: *Compiled to meet __ (meters, feet) horizontal accuracy at 95 percent confidence level*."
- Paragraph 1.2, Horizontal Accuracy, of *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS) in 2004, further explains why it is difficult and impractical to test the horizontal

accuracy of LiDAR data, and explains why ASPRS does not require horizontal accuracy testing of LiDAR-derived elevation products.

- ASPRS has been actively seeking to develop cost-effective techniques to use LiDAR intensity imagery to test the horizontal accuracy of LiDAR data. As recently as May 1, 2008, at the annual conference of ASPRS, the most relevant technique for doing so was in a paper entitled "New Horizontal Accuracy Assessment Tools and Techniques for Lidar Data," presented by the Ohio DOT. Whereas the technique had research value, it was neither practical nor affordable for use in horizontal accuracy testing of FDEM data.
- Appendix A of FDEM's Baseline Specifications require 20 horizontal test points for every 500 square mile area of digital orthophotos to be produced, and Appendix B of FDEM's Baseline Specifications requires 120 vertical test points for each 500 square mile area of LiDAR data to be produced. The PDS task orders included no funding for the more-expensive horizontal checkpoints that would be certain to appear on LiDAR intensity images as clearly-defined point features.
- In addition to LiDAR system factory calibration of horizontal and vertical accuracy, each of the PDS team's LiDAR subcontractors have different techniques for field calibration checks used to determine if bore-sighting is still accurate. Terrapoint's technique, used for Clay-Putnam Counties, is explained in the LiDAR Processing Report at Appendix D.

LiDAR Qualitative Assessments

In addition to vertical accuracy testing, URS also performed the LiDAR qualitative assessment.

An assessment of the vertical accuracy alone does not yield a complete picture with regard to the usability of LiDAR data for its intended purpose. It is very possible for a given set of LiDAR data to meet the accuracy requirements, yet still contain artifacts (non-ground points) in the bare-earth surface, or a lack of ground points in some areas that may render the data, in whole or in part, unsuitable for certain applications.

Based on the extremely large volume of elevation points generated, it is neither time efficient, cost effective, nor technically practical to produce a perfectly clean (artifact-free) bare-earth terrain surface. The purpose of the LiDAR Qualitative Assessment Report (see Appendix G) is to provide a qualitative analysis of the "cleanliness" of the bare-earth terrain surface for use in supporting riverine and coastal analysis, modeling, and mapping.

The main software programs used by URS in performing the bare-earth data cleanliness review include the following:

- *GeoCue*: a geospatial data/process management system especially suited to managing large LiDAR data sets
- *TerraModeler*: used for analysis and visualization
- *TerraScan*: runs inside of MicroStation; used for point classification and points file generation
- *GeoCue LAS EQC:* is also used for data analysis and edit

The following systematic approach was followed by URS in performing the cleanliness review and analysis:

- Uploaded data to the GeoCue data warehouse (enhanced data management)

- LiDAR: cut the data into uniform tiles measuring 5,000 feet by 5,000 feet – using the State Plane tile index provided by FDEM
    - Imagery: Best available orthophotography was used to facilitate the data review. Additional LiDAR Orthos were created from the LiDAR intensity data and used for review purposes.
- Performed coverage/gap check to ensure proper coverage of the project area
    - Created a large post grid (~30 meters) from the bare-earth points, which was used to identify any holes or gaps in the data coverage.
- Performed tile-by-tile analyses
    - Using TerraScan and LAS EQC, checked for gross errors in profile mode (noise, high and low points)
    - Reviewed each tile for anomalies; identified problem areas with a polygon, annotated comment, and screenshot as needed for clarification and illustration. Used ortho imagery when necessary to aid in making final determinations with regards to:
        - Buildings left in the bare-earth points file
        - Vegetation left in the bare-earth points file
        - Water points left in the bare-earth points file
        - Proper definition of roads
        - Bridges and large box culverts removed from the bare-earth points file
        - Areas that may have been "shaved off" or "over-smoothed" during the auto-filtering process
- Prepared and sent the error reports to LiDAR firm for correction
- Reviewed revisions and comments from the LiDAR firm
- Prepared and submitted final reports to FDEM

Breakline Production Methodology

For the *hard breaklines*, Dewberry used GeoCue software to develop LiDAR stereo models of Clay and Putnam counties so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Dewberry stereo-compiled the eight types of *hard breaklines* in accordance with the Data Dictionary at Appendix C. For the *soft hydro breaklines*, Dewberry used 2.5-D techniques to digitize soft, linear hydrographic features first in 2-D and then used its GeoFIRM toolkit to drape the soft breaklines over the ESRI Terrain to derive the Z-values (elevations), also consistent with the Data Dictionary at Appendix C. All breakline compilation was performed under the direct supervision of an ASPRS Certified Photogrammetrist and Florida Professional Surveyor and Mapper (PSM). The breaklines conform with data format requirements outlined by the FDEM Baseline Specifications.

Whereas flowing rivers and streams are "hydro-enforced" to depict the downward flow of water, dry drainage features are not "hydro-enforced" but deliberately include undulations that more-accurately represent the true topography. This is, in fact, the ideal situation for topographic mapping.

The five figures below demonstrate how the PDS team's high LiDAR point density (4 points per square meter) are used to penetrate dense vegetation and accurately map the dry drainage feature not visible from a normal digital orthophoto (Figure 1); the total density of the LiDAR point cloud (Figure 2); the density of LAS Class 2 points that penetrated to the ground (Figure 3); the color-coded Terrain to help in visualizing the variable elevations (Figure 4); and the soft hydro breakline that approximates the potential flow line of the dry drainage feature and the contours that clearly show the undulations in the Terrain (Figure 5). At Figure 5, the 9-foot contour lines are *depression contours* that surround elevation points that are lower than 9-feet. Although the undulations, by definition, are not "hydro-enforced," the PDS Team's PSM in responsible charge of this project considers it a violation of professional standards if one were to deliberately degrade the accurate Terrain, soft hydro breakline and contours in a dry drainage feature in order to "hydro-enforce" that feature by filling the depressions and falsely scalping off the higher undulations in order to make an idealized monotonic dry streambed out of the true undulating streambed. To "hydro-enforce" such a dry streambed would be to falsify the true topography of naturally undulating terrain. The soft hydro breaklines are part of the hydrographic feature class, but have a separate sub-class code, 3. This enables hydro-enforced hydrographic features, sub-class codes 1 and 2 for single and dual lines, to be distinguished from these non-hydro-enforced soft hydrographic features representing dry drainage features.

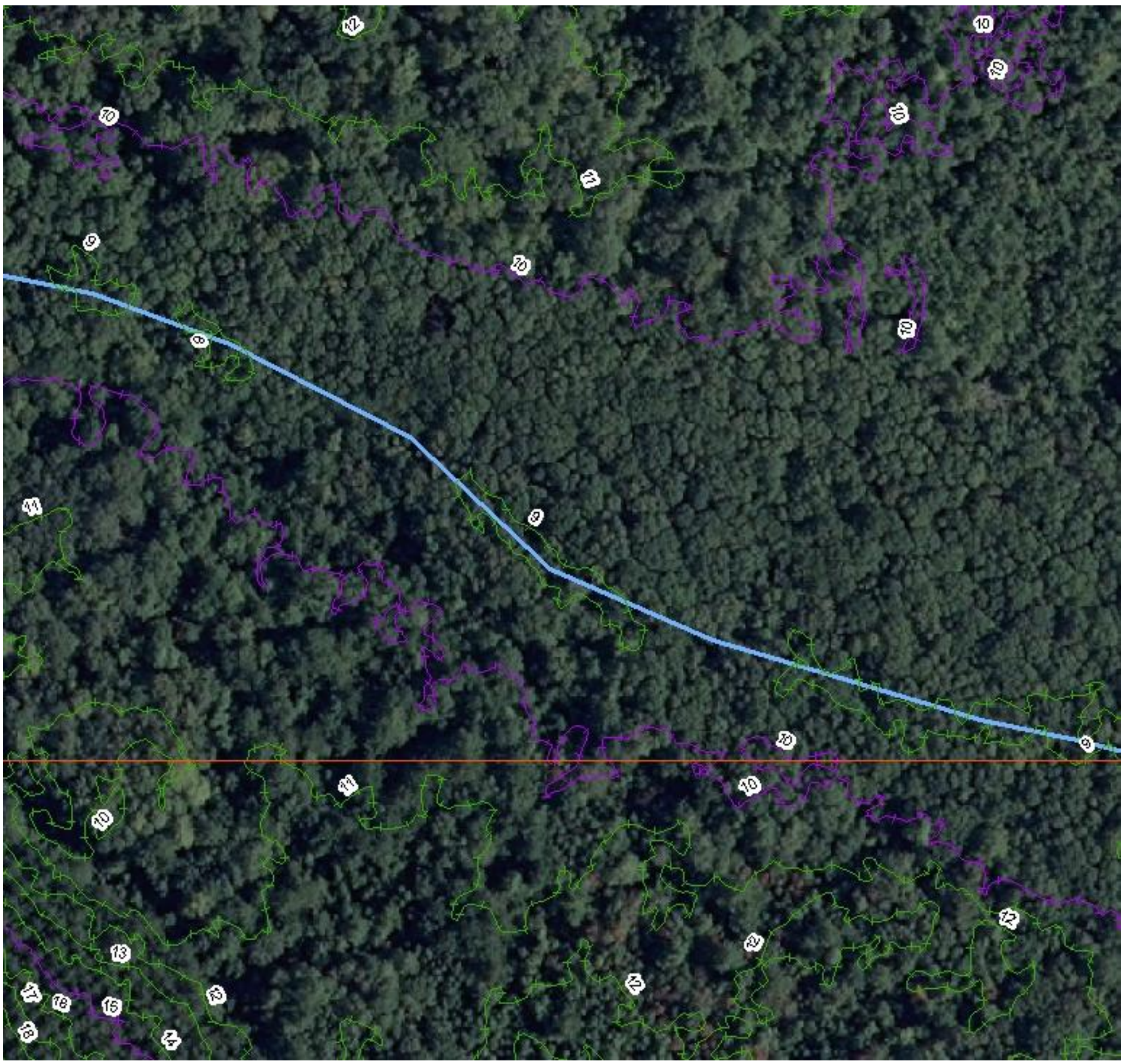


Figure 1. Even in very dense vegetation, the PDS team's high LiDAR point density (4 points per square meter) enabled the detection of dry drainage features beneath the vegetation.

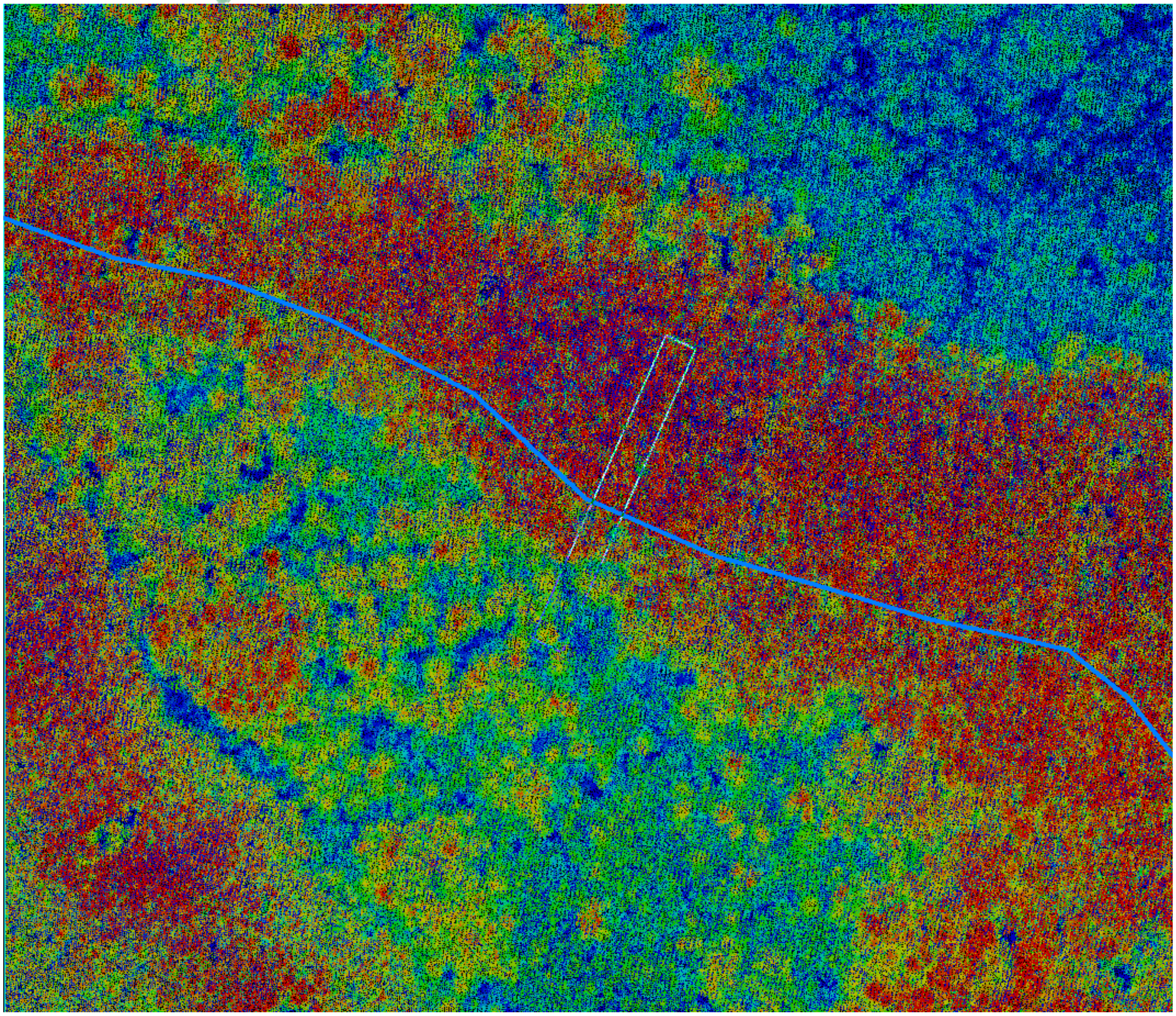
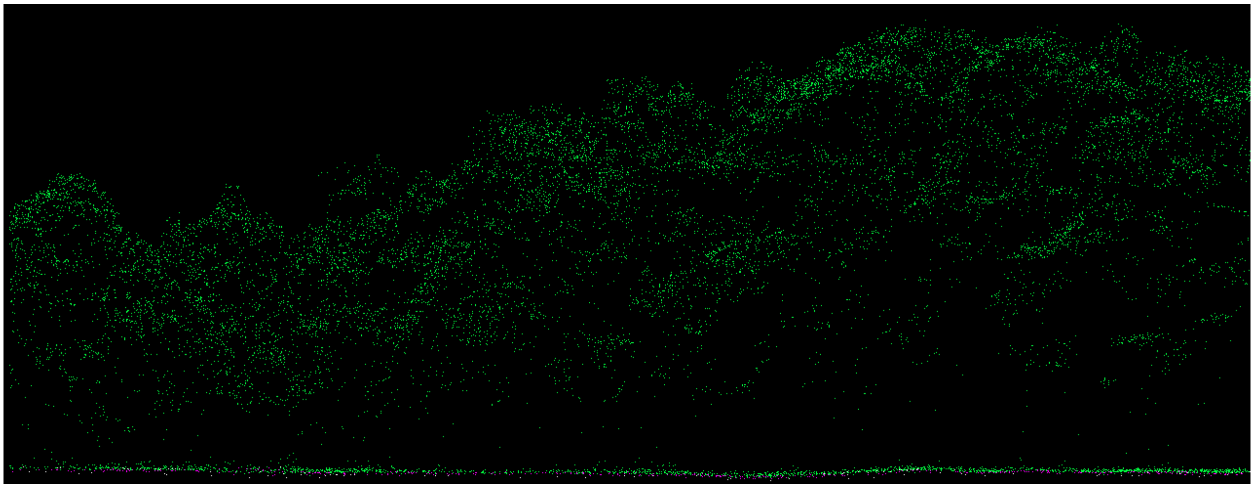


Figure 2. Full point cloud with profile (below) showing density of vegetation in the area of the dry drainage feature.



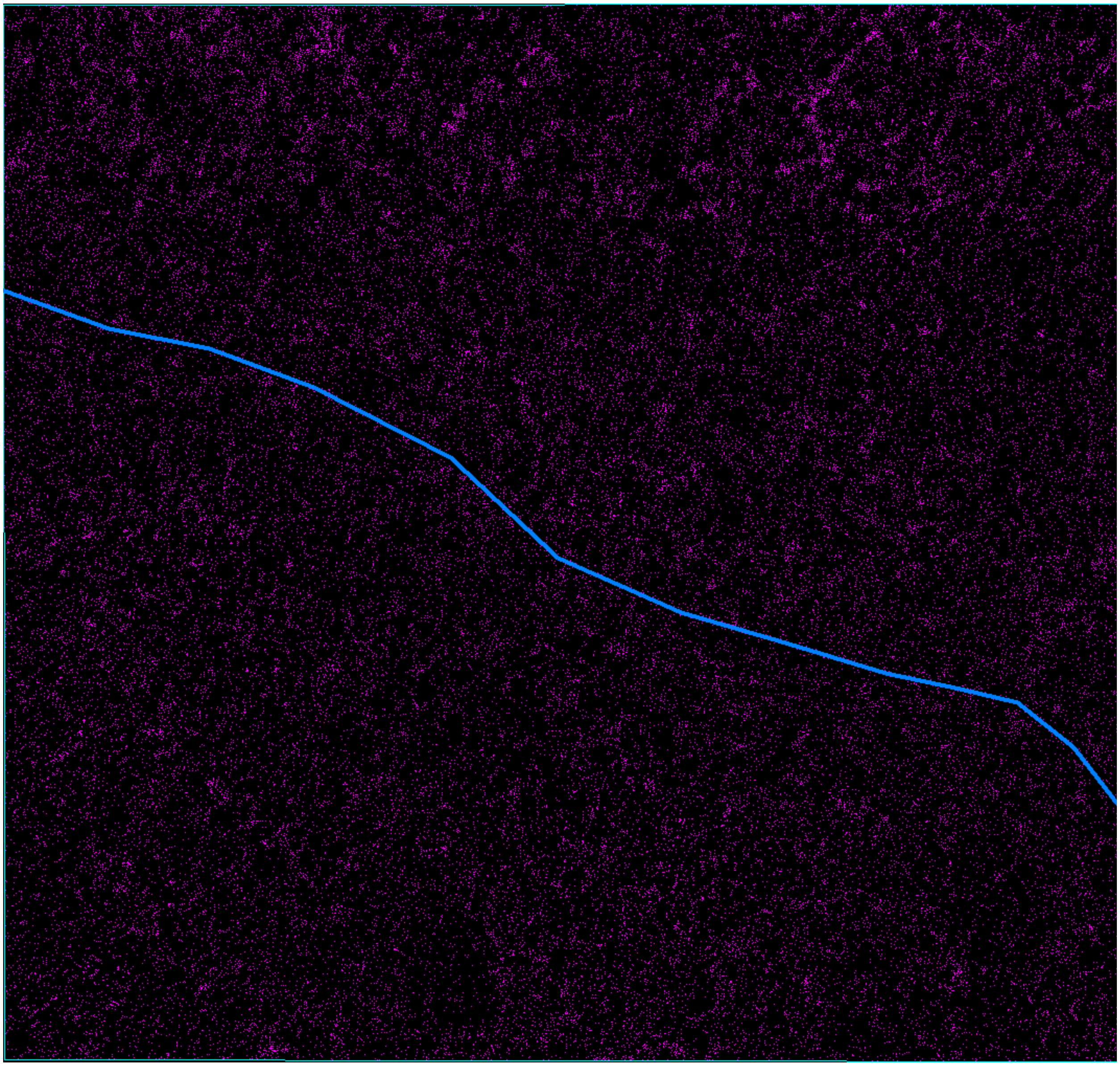


Figure 3. LAS Class 2 (ground) points showing the high density of points that penetrated the vegetation.

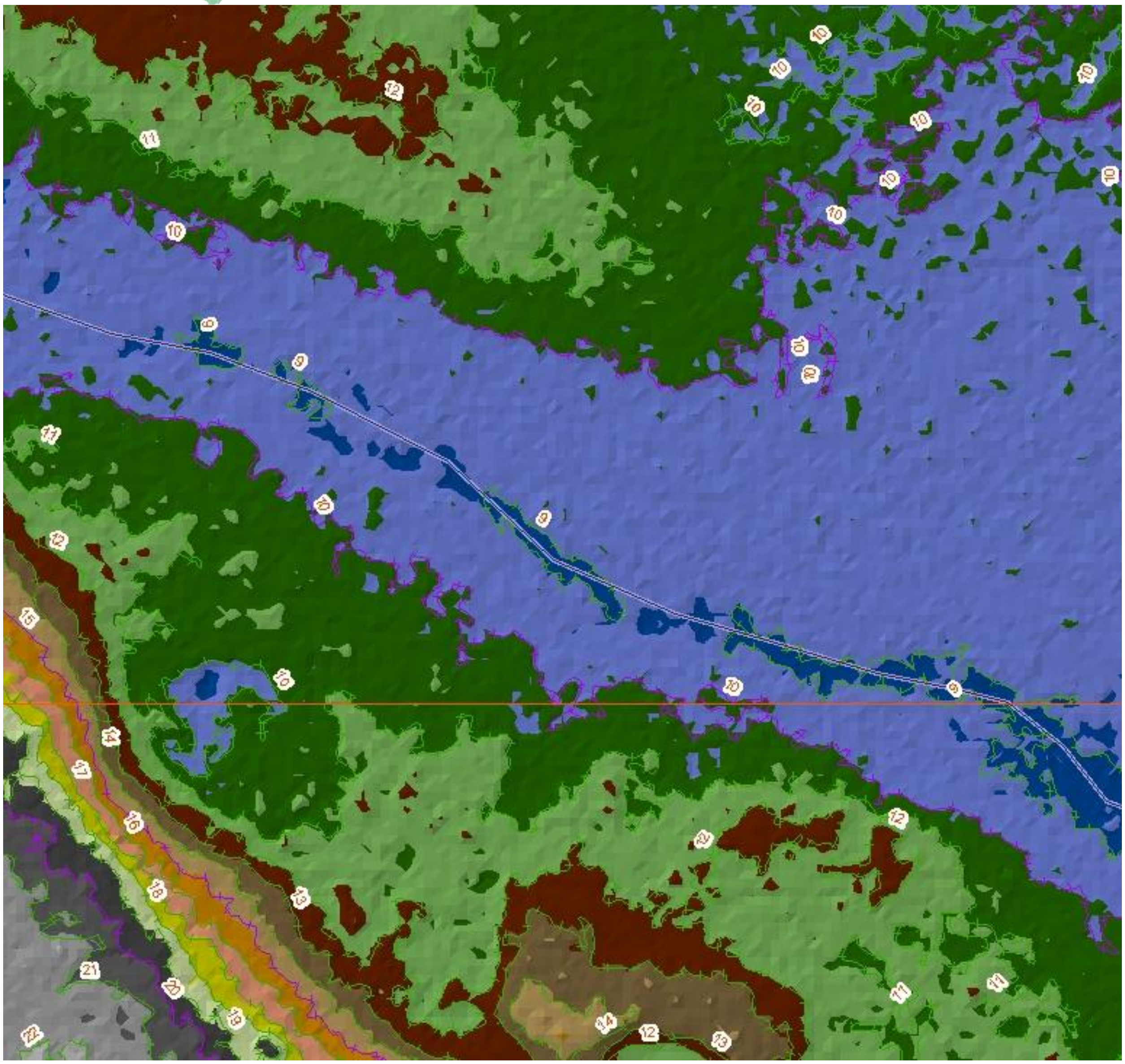


Figure 4. The ESRI Terrain is color-coded to depict the variable elevation bands. This clearly shows the lower, undulating elevations in the dry drainage feature.

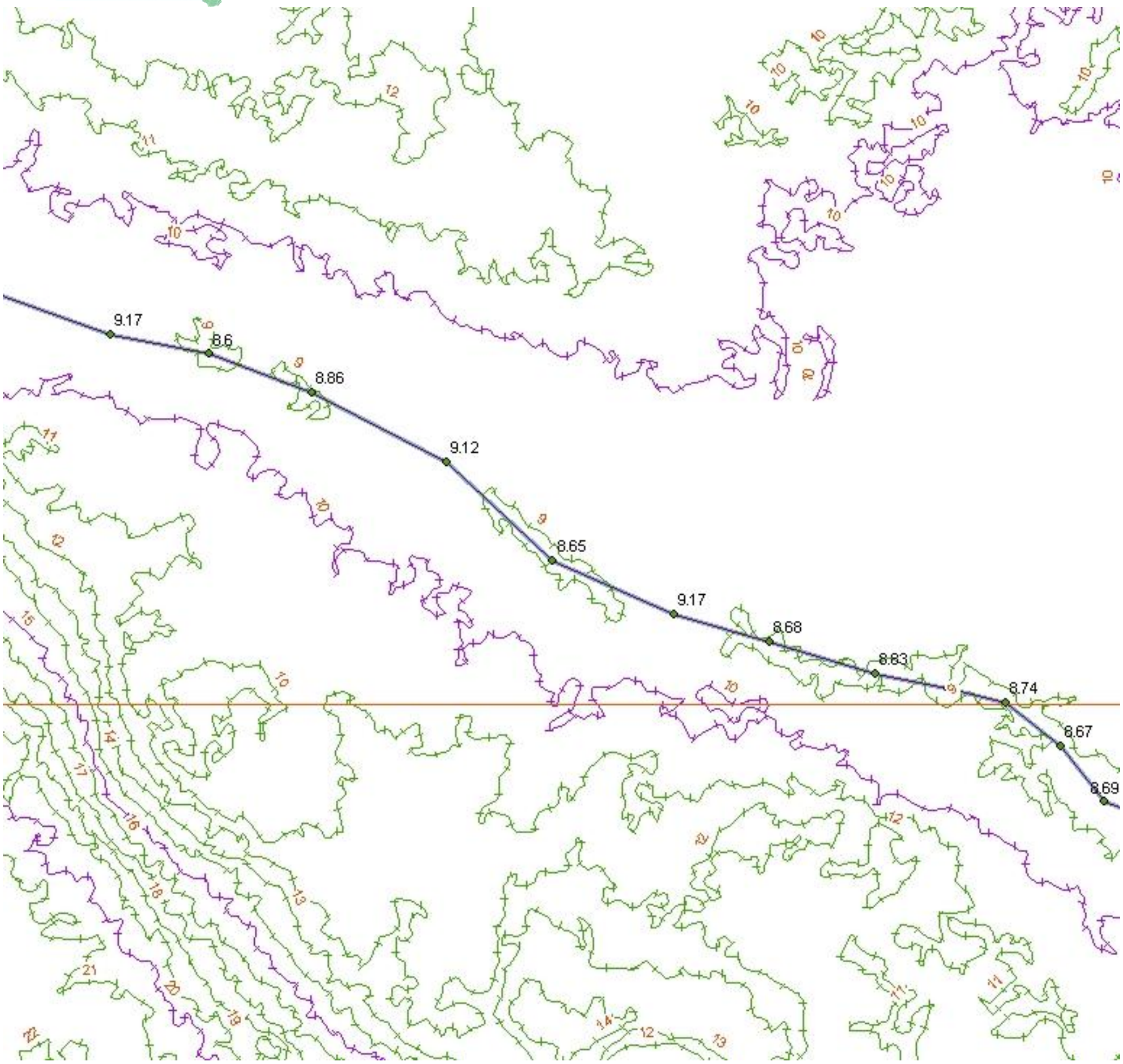


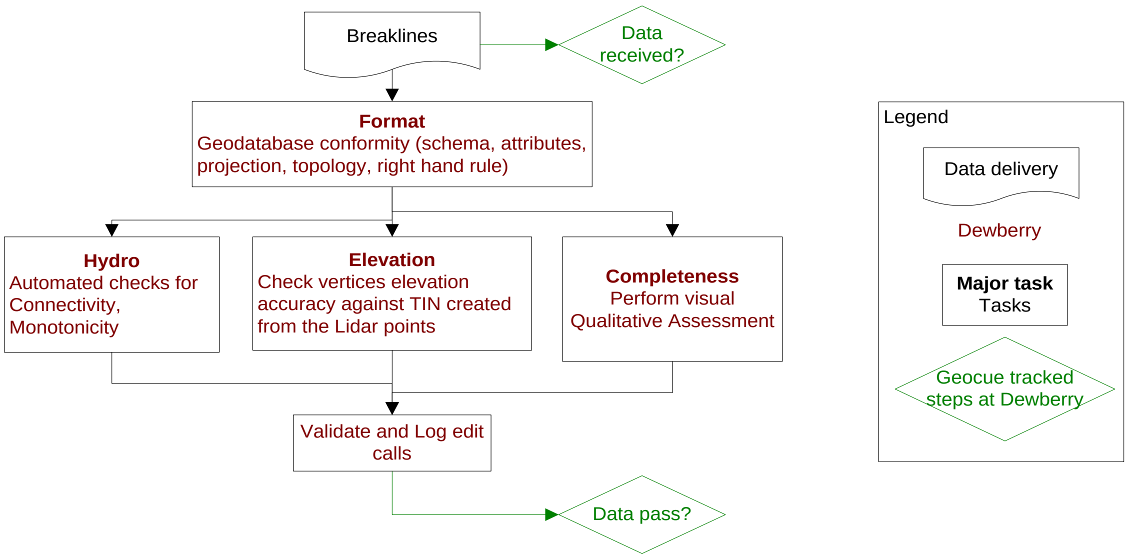
Figure 5. This figure shows variable "invert elevations" along the soft hydro breakline. It also shows "depression contours" where water would normally puddle if the drainage feature was only half dry. The soft hydro breakline passing through the "depression contours" clearly depict elevations lower than the 9-foot contour lines.

Contour Production Methodology

Using proprietary procedures developed by Dewberry, the 2-foot and 1-foot contours were compiled from the breaklines and LiDAR data in accordance with the Data Dictionary at Appendix C. The contours conform with data format requirements outlined by the FDEM Baseline Specifications.

Breakline Qualitative Assessments

Dewberry performed the breakline qualitative assessments. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.



In order to ensure a correct database format, Dewberry provided all subcontractors with geodatabase shells containing the required feature classes in the required format. Upon receipt of the data, Dewberry verified that the correct shell was used and validated the topology rules associated with it.

Feature Class	Rule	Feature Class
SOFTFEATURE	Must Not Intersect	
OVERPASS	Must Not Intersect	
ROADBREAKLINE	Must Not Intersect	
HYDROGRAPHIC...	Must Not Intersect	
SOFTFEATURE	Must Not Overlap With	ROADBREAKLINE
SOFTFEATURE	Must Not Overlap With	HYDROGRAPHICF
ROADBREAKLINE	Must Not Overlap With	HYDROGRAPHICF
SOFTFEATURE	Must Not Self-Intersect	
OVERPASS	Must Not Self-Intersect	
ROADBREAKLINE	Must Not Self-Intersect	
HYDROGRAPHIC...	Must Not Self-Intersect	

Breaklines topology rules

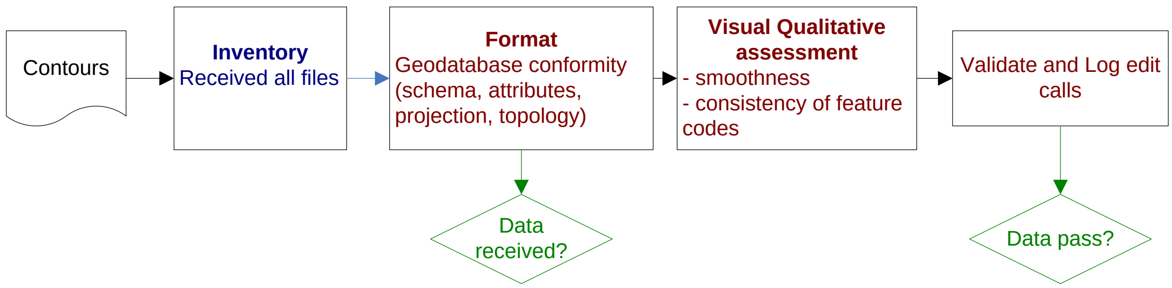
Then automated checks are applied on hydrofeatures to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the elevation extracted from the TIN built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations do not differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis of the breaklines. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations.

Contour Qualitative Assessments

Dewberry also performed the qualitative assessments of the contours using the following workflow.



Upon receipt of each delivery area, the first step performed by Dewberry was a series of data topology validations. Dewberry checked for the following instances in the data:

1. Contours must not overlap
2. Contours must not intersect
3. Contours must not have dangles (except at project boundary)
4. Contours must not self-overlap
5. Contours must not self-intersect

After the topology and geodatabase format validation was complete, Dewberry checked the elevation attribute of each contour to ensure NULL values are not included. Finally, Dewberry loaded the contour data plus the Lidar intensity images into ArcGIS and performed a full qualitative review of the contour data for smoothness and consistency of feature codes.

Appendix H summarizes Dewberry's qualitative assessments of the breaklines and contours, with graphic examples of what the breaklines and contours look like.

Deliverables

Except for the two Final Reports of Specific Purpose Survey, LiDAR & Photogrammetry Checkpoints for Clay County and Putnam County, Florida, both dated March 26, 2008, delivered separately by PBS&J, the deliverables listed at Table 2 are included on the external hard drive that accompanies this report.

Table 2. Summary of Deliverables

Copies	Deliverable Description	Format	Location
2	Final Reports of Specific Purpose Survey, LiDAR & Photogrammetry Checkpoints, Clay County and Putnam County, Florida, dated March 26, 2008	Hardcopy and pdf	Submitted separately
1	Data Dictionary	pdf	Appendix C
3	LiDAR Processing Report	Hardcopy and pdf	Appendix D
3	LiDAR Vertical Accuracy Report	Hardcopy and pdf	Appendix F
1	LiDAR Qualitative Assessment Report	pdf	Appendix G
1	Breakline/Contour Qualitative Assessment Report	pdf	Appendix H
1	Breaklines, Contours, Network-Adjusted Control Points, Vertical accuracy checkpoints, Tiling Footprint, Lidar ground masspoints	Geodatabase	Submitted separately

References

ASPRS, 2007, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

ASPRS, 2004, *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, May 24, 2004, http://www.asprs.org/society/committees/lidar/downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf.

Bureau of the Budget, 1947, *National Map Accuracy Standards*, Office of Management and Budget, Washington, D.C.

FDEM, 2006, Florida GIS, *Baseline Specifications for Orthophotography and LiDAR*, Appendix B, *Terrestrial LiDAR Specifications*, Florida Division of Emergency Management, Tallahassee, FL, October, 2006.

FEMA, 2004, Appendix A, *Guidance for Aerial Mapping and Surveying*, to "Guidelines and Specifications for Flood Hazard Mapping Partners," Federal Emergency Management Agency, Washington, D.C.

FGCC, 1984, *Standards and Specifications for Geodetic Control Networks*, Federal Geodetic Control Committee, Silver Spring, ,MD, reprinted August 1993.

FGCC, 1988, *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques*, Federal Geodetic Control Committee, Silver Spring, MD, reprinted with corrections, August, 1989.

FGDC, 1998a, *Geospatial Positioning Accuracy Standards, Part I: Reporting Methodology*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/.

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 2, Standards for Geodetic Networks*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 3, National Standard for Spatial Data Accuracy*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998d, Content Standard for Digital Geospatial Metadata (CSDGM), Federal Geographic Data Committee, c/o USGS, Reston, VA, www.fgdc.gov/metadata/contstan.html.

NDEP, 2004, *Guidelines for Digital Elevation Data*, Version 1.0, National Digital Elevation Program, May 10, 2004, http://www.ndep.gov/

NOAA, 1997, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm),* NOAA Technical Memorandum NOS NGS-58, November, 1997.

General Notes

This report is incomplete without the external hard drives of the LiDAR masspoints, breaklines, contours, and control. See the Geodatabase structure at Appendix I.

This digital mapping data complies with the Federal Emergency Management Agency (FEMA) “Guidelines and Specifications for Flood Hazard Mapping Partners,” Appendix A: *Guidance for Aerial Mapping and Surveying.*

The LiDAR vertical accuracy report at Appendix F does not conform with the National Standard for Spatial Data Accuracy (NSSDA) because fewer than 20 checkpoints were available to test the individual land cover categories.

The digital mapping data is certified to conform to Appendix B, *Terrestrial LiDAR Specifications*, of the “Florida Baseline Specifications for Orthophotography and LiDAR.” This report is certified to conform with Chapter 61G17-6, Minimum Technical Standards, of the Florida Administrative Code, as pertains to a Specific Purpose LiDAR Survey.

THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA PROFESSIONAL SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

Surveyor and Mapper in Responsible Charge:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Professional Surveyor and Mapper
License #LS6659

Signed: ________________________________ Date: ________________


DAVID F. MAUNE
LICENSE NUMBER
LS6659
STATE OF
FLORIDA
PROFESSIONAL SURVEYOR & MAPPER

List of Appendices

A. Project Tiling Footprint

B. Geodetic Control Point

C. Data Dictionary

D. LiDAR Processing Report

E. QA/QC Checkpoints and Associated Discrepancies

F. LiDAR Vertical Accuracy Report

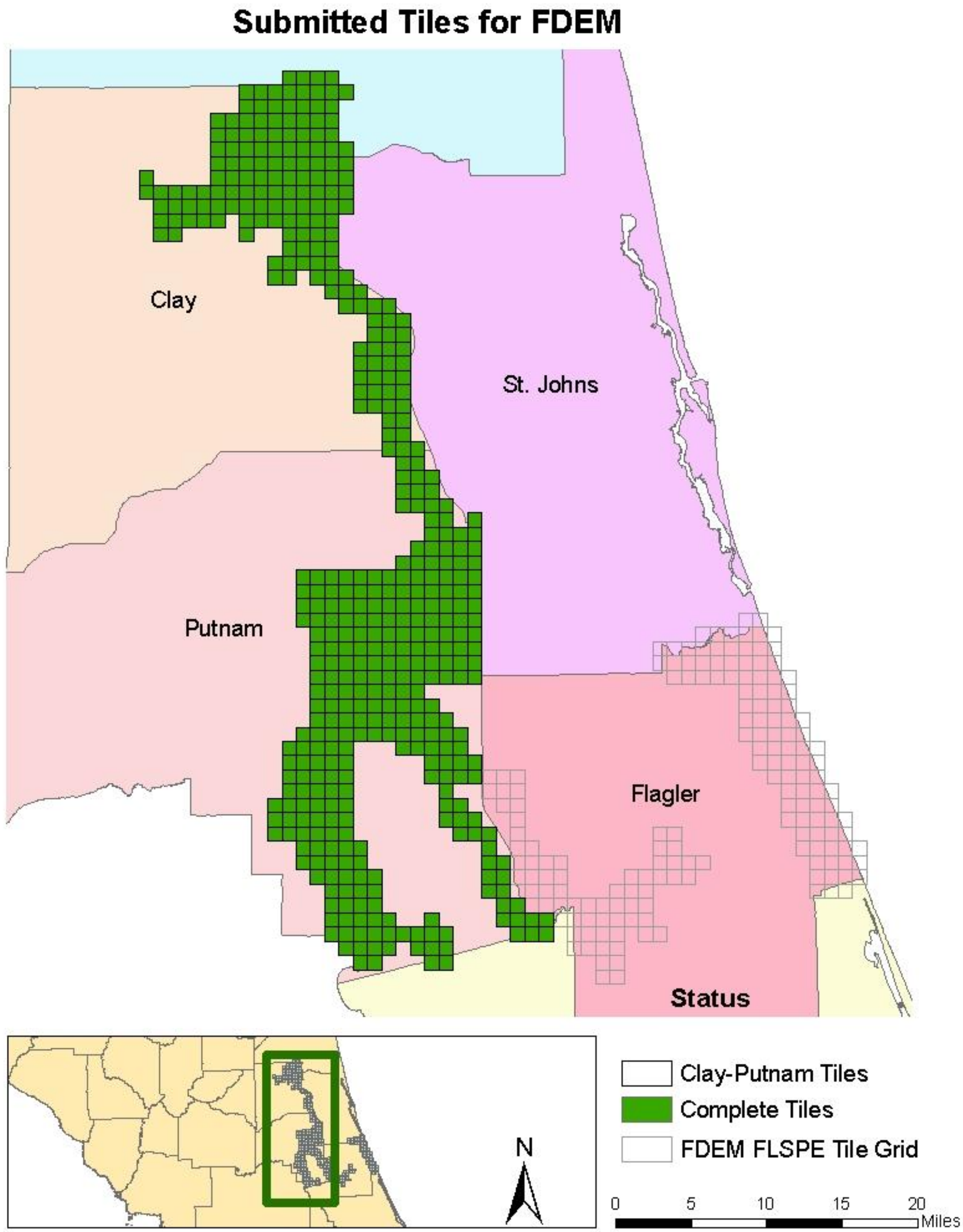
G. LiDAR Qualitative Assessment Report

H. Breakline/Contour Qualitative Assessment Report

I. Geodatabase Structure

Appendix A: Project Tiling Footprint

464 Tiles delivered for Clay-Putnam Counties



List of delivered Tiles (464):

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024751_E	022648_E	022952_E	027159_E	032559_E	032261_E
024752_E	022649_E	022953_E	028359_E	032560_E	032263_E
024141_E	022650_E	022954_E	029258_E	032561_E	032264_E
024148_E	023246_E	023254_E	029259_E	032562_E	032852_E
024149_E	023247_E	024151_E	026858_E	032563_E	032854_E
024150_E	023248_E	024152_E	028956_E	032564_E	032859_E
024745_E	023253_E	024153_E	028958_E	034064_E	032861_E
024746_E	023547_E	024441_E	027457_E	031962_E	032863_E
024747_E	023548_E	024442_E	027459_E	031963_E	032864_E
024748_E	023549_E	024447_E	027756_E	031964_E	033152_E
024753_E	023550_E	024448_E	027758_E	031961_E	033153_E
024754_E	023551_E	024449_E	028657_E	031960_E	033154_E
024755_E	023552_E	024450_E	028659_E	034057_E	033156_E
023846_E	023553_E	024455_E	028356_E	034058_E	033158_E
023847_E	023554_E	025042_E	028358_E	034059_E	033163_E
023848_E	023555_E	025044_E	026857_E	034060_E	033754_E
023849_E	028059_E	025046_E	028957_E	033457_E	033756_E
023854_E	022354_E	025051_E	028959_E	030759_E	033758_E
023855_E	022355_E	025053_E	026554_E	030761_E	033759_E
025651_E	022651_E	026254_E	027458_E	033453_E	033760_E
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023850_E	025342_E	024444_E	029559_E	031062_E	032862_E
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040355_E

Appendix B: Geodetic Control Point

As indicated in PBS&J's "Final Report of Specific Purpose Survey, LiDAR & Photogrammetry Checkpoints, for Clay County, Florida," dated March 26, 2008, the following National Spatial Reference System (NSRS) control stations were used to control the LiDAR survey and/or QA/QC checkpoint surveys in Clay County:

PointID	Northing(ft)	Easting(ft)	Z(ft)
AA8133	1971375.9	485983.94	3.04
AA8134	1969096.9	483555.408	4.85
AA8148	1965640.4	451572.099	62.43
AC5768	2119832.8	430561.362	8.05
AC5771	2130323	433259.994	33.15
AC9031	2032230	449639.281	13.9
AQ1552	2056697.3	446260.624	7.6
DE6007	2236648.1	435205.019	34.616
717703	2056605.3	445646.48	5.892

As indicated in PBS&J's "Final Report of Specific Purpose Survey, LiDAR & Photogrammetry Checkpoints, for Clay County, Florida," dated March 26, 2008, the following National Spatial Reference System (NSRS) control stations were used to control the LiDAR survey and/or QA/QC checkpoint surveys in Putnam County:

PointID	Northing(ft)	Easting(ft)	Z(ft)
AA8131	1901642.377	424098.317	25.21
AA8133	1971375.879	485983.94	3.04
AA8134	1969096.904	483555.408	4.85
AA8140	1843850.066	493067.559	54
AA8148	1965640.422	451572.099	62.43
AA8156	1903416.142	425796.52	26.56
AC9042	1958795.055	448165.592	24.94
AC9058	1932986.331	456931.637	3.02
AC9832	1870060.929	420970.047	10.52
AI9208	1828048.285	494770.054	40.73
AQ0048	1942745.655	428931.463	12.06
AQ2556	1901725.71	446959.623	48.6
DE6786	1889170.357	492827.213	16.52
DE8607	1868592.301	486372.177	10.99
DG5869	1836218.861	455613.481	16.88
717704	1893019.464	450926.264	74.586

AA8134	1969097.01	483555.473	4.849
AA8146	1938747.587	447422.954	19.521
DE6012	1938161.311	437738.193	34.131
DF5773	1804732.04	621458.18	33.251

The NSRS Data Sheets for each of these control stations are included in the referenced reports from PBS&J.

Appendix C: Data Dictionary

LiDARgrammetry Data Dictionary & Stereo Compilation Rules

FINAL

FDEM (Florida Department of Emergency Management)

January 25, 2008

Table of Contents

Horizontal and Vertical Datum

Horizontal datum shall be referenced to the appropriate Florida State Plane Coordinate System. The horizontal datum shall be North American Datum of 1983/HARN adjustment in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). Geoid03 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to the appropriate Florida State Plane Coordinate System Zone, Units in US Survey Feet.

Contour Topology Rules

The following contour topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: CONTOURS_Topology				Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
CONTOUR_1FT	5	1	1	No
CONTOUR_2FT	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Origin (*FeatureClass::Subtype*)	Destination (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All

Breakline Topology Rules

The following breakline topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
OVERPASS	5	1	1	No
ROADBREAKLINE	5	1	1	No
SOFTFEATURE	5	1	1	No

Topology Rules

Name	**Rule Type**	**Trigger Event**	**Origin** (*FeatureClass::Subtype*)	**Destination** (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	OVERPASS::All	OVERPASS::All
Must not intersect	The rule is a line-no intersection rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	ROADBREAKLINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	OVERPASS::All	OVERPASS::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Coastal Shoreline

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: COASTALSHORELINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will outline the land / water interface at the time of LiDAR acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Coast	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Coastal Shoreline	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may require some feathering or edge matching to ensure a smooth transition. Orthophotography will not be use to delineate this shoreline.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. For the polygon closure vertices and segments, null values or a value of 0 are acceptable since this is not an actual shoreline. The digital orthophotography is not a suitable source for capturing this feature. Efforts should be taken to gradually feather the difference between tidal conditions of neighboring flights. Stair-stepping of the breakline feature will not be allowed. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water

			where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Linear Hydrographic Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: HYDROGRAPHICFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict linear hydrographic features with a length of 0.5 miles or longer as breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	HydroL	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Single Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, embankments, etc. with an average width less than or equal to 8 feet. . In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line. Each vertex placed should maintain vertical integrity.
2	Dual Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, etc. with an average width greater than 8 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class.	Capture features showing dual line (one on each side of the feature). Average width shall be great than 8 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is not required to show “closed polygon”. These instructions are only for docks or piers that follow

			the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.
3	Soft Hydro Single Line Feature	Linear hydro features with an average width less than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line.
4	Soft Hydro Dual Line Feature	Linear hydro features with an average width greater than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 8 feet to show as a double line. Data is not required to show "closed polygon".

Note: Carry through bridges for all linear hydrographic features.

Closed Water Body Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: WATERBODY
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict closed water body features and will have the associated water elevation available as an attribute.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
WATERBODY_ELEVATION_MS	Double	Yes			0	0		Assigned by PDS
TYPE	Long Integer	No	1	HydroP	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Water Body	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features one-half acres in size or greater. “Donuts” will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. The field “WATERBODY_ELEVATION_MS” shall be automatically computed from the z-value of the vertices. An Island within a Closed Water Body Feature will also have a “donut polygon” compiled in addition to an Island polygon. These instructions are only for docks or piers that follow

			the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Road Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ROADBREAKLINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict apparent edge or road pavement as breaklines but will not include bridges or overpasses.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Road	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Edge of Pavement	Capture edge of pavement (non-paved or compact surfaces as open to compiler interpretability) on both sides of the road. Runways are not to be included.	DO NOT INCLUDE Bridges or Overpasses within this feature type. Capture apparent edge of pavement (including paved shoulders). Each vertex placed should maintain vertical integrity and data is not required to show "closed polygon". Box culverts should be continued as edge of pavement unless a clear guardrail system is in place; in that case, feature should be shown as bridge / overpass.

Bridge and Overpass Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: OVERPASS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict bridges and overpasses as separate entities from the edge of pavement feature class.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Bridge	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bridge Overpass	Feature should show edge of bridge or overpass.	Capture apparent edge of pavement on bridges or overpasses. Do not capture guard rails or non-drivable surfaces such as sidewalks. Capture edge of drivable pavement only. Each vertex placed should maintain vertical integrity and data is not required to show “closed polygon”. Box culverts should be captured in this feature class if a clear guardrail system is in place; otherwise, show as edge-of-pavement.

Soft Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: SOFTFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict soft changes in the terrain to support better hydrological modeling of the LiDAR data and sub-sequent contours.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Soft	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Soft Breakline	Supplemental breaklines where LiDAR mass points are not sufficient to create a hydrologically correct DTM. Soft features shall include ridges, valleys, top of banks, etc. Soft features may also include natural Embankments that act as small ponding areas. Top of Banks can also be included in the soft breakline class so long as it does not define the edge of a water feature.	Capture breaklines to depict soft changes in the elevation. If the elevation changes are easily visible, go light on the breakline capture. Each vertex placed should maintain vertical integrity.

Island Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ISLAND
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict natural and man-made islands as closed polygons.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Island	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Island	Apparent boundary of natural or man-made island feature captured with a constant elevation. Island features will be captured for features one-half acres in size or greater.	Island shall take precedence over Coastal Shore Line Features. Islands shall be captured as closed polygons with the land feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed around the island. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated

			headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Low Confidence Areas

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONFIDENCE
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation meaning that the resultant contours may not meet the required accuracy specifications.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	Apparent boundary of vegetated areas that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. These features are for reference only to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.	Capture as closed polygon with the obscured area to the right of the line. Compiler does not need to worry about z-values of vertices; feature class will be 2-D only.

Note: Area must be ½ acre or larger. Only outline areas where you are not sure about vegetative penetration of the LiDAR data. This is not the same as a traditional obscured area.

Masspoints

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: MASSPOINT
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts masspoints as determined by the LiDAR ground points (LAS Class 2).

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Masspoint	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Masspoint	Only the bare earth classification (Class 2) shall be loaded into the MASSPOINT feature class.	None. Data should be loaded from LAS Class 2 (Ground)

1 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_1FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1' contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between. If the horizontal distance between two adjacent contours is

		unduly prominent on the published map.	larger than 1” at map scale (100’), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200’.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

2 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_2FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1' contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between.

		shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map.	If the horizontal distance between two adjacent contours is larger than 1” at map scale (100’), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200’.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

Ground Control

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: GROUNDCONTROL
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used in the acquisition and calibration of the LiDAR and aerial photography collected by Aero-Metric, Sanborn and Terrapoint.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Control	0	0		Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Control Point	Primary or Secondary PDS control points used for either base station operations or in the calibration and adjustment of the control.	None.

Vertical Accuracy Test Points

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: VERTACCTESTPTS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used by PDS to test the vertical accuracy of the data produced.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS
LANDCOVER	Long Integer	No	1	dLANDCOVERTYPE	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bare-Earth and Low Grass	None.	None.
2	Brush Lands and Low Trees	None.	None.
3	Forested Areas Fully Covered by Trees	None.	None.
4	Urban Areas	None.	None.

Footprint (Tile Boundaries)

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: FOOTPRINT
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class includes the Florida 5,000' x 5,000' tiles for each countywide geodatabase produced.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
CELLNUM	String	No			0	0	8	Assigned by PDS

Contact Information

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Appendix D: LiDAR Processing Report

PROJECT REPORT

Terrapoint #: 2008-113-U
Dewberry #: 07-HS-34-14-00-22-469 Task Order 20070525-4927
Florida (Clay Putnam, Lot 2) 2007 LiDAR Collection
Originally submitted: 2008-10-10
Revisions: 2008-10-31

Presented to:

Dewberry
Fairfax, Virginia

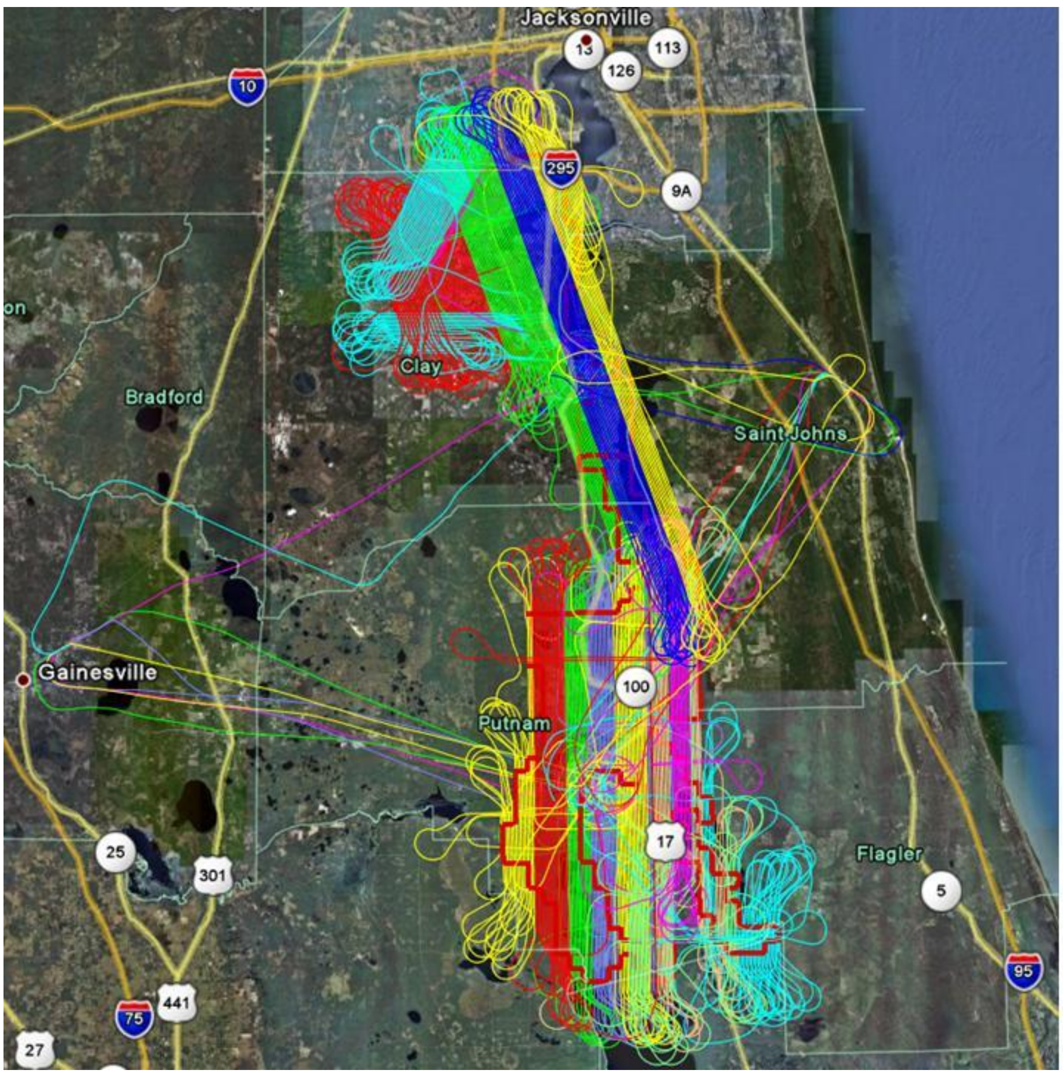
Submitted by:

Terrapoint
Houston, Texas

EXECUTIVE SUMMARY

This LiDAR project was to provide high accuracy, classified multiple return LiDAR, for 420.576 square miles, of the Clay-Putnam Counties, FL. The LiDAR data were acquired and processed by Terrapoint USA to support FDEM. The product is a high density mass point dataset with an average point spacing of $1m^2$. The data is tiled without a buffer, stored in LAS 1.1 format, and LiDAR returns are classified in 4 ASPRS classes: Unclassified (1), Ground (2), Noise (7) and Water (9), Overlap (12).

The flight lines and dates are shown in the image below, to include the field-calibration/bore-sight flights.

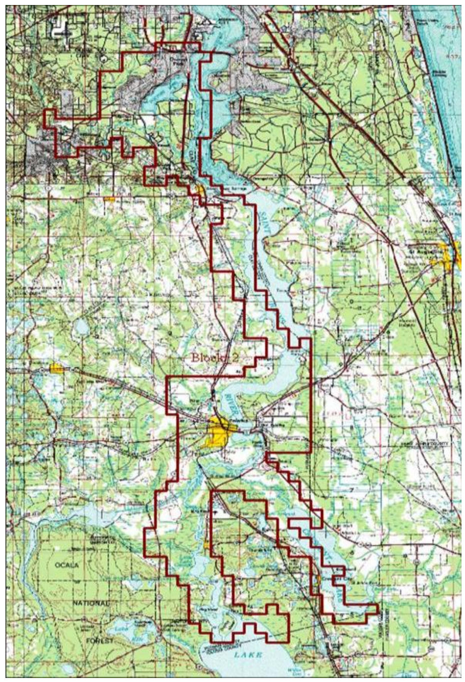


LEGEND		
Mission No	Date Flown	Color Code
o107249a	9/6/2007	1
o107249b	9/6/2007	4
o107250a	9/7/2007	2
o307251a	9/8/2007	9
o107252a	9/9/2007	244
o107253a	9/10/2007	243
o107254a	9/11/2007	242
o307255a	9/12/2007	223
o307256a	9/13/2007	191
o208032b	2/1/2008	31
o208033a	2/2/2008	158
o208033b	2/2/2008	170
o208034a	2/3/2008	137
o208040a	2/9/2008	5
o208041a	2/10/2008	241
o208042c	2/11/2008	95

The elevation data was verified internally prior to delivery to ensure it met fundamental accuracy requirements when compared kinematic to Terrapoint GPS checkpoints. Below is the summary for the project site.

- The Raw elevation measurements for Clay-Putnam Counties, Lot 2, has been tested to (0.257), in US Survey feet for vertical accuracy at 95 percent confidence level.

All data delivered meets and exceeds Terrapoint's deliverable product requirements as setout by Terrapoint's IPROVE program.



Clay-Putnam Counties, Lot 2 Project Report

Introduction

LiDAR data is remotely sensed high-resolution elevation data collected by an airborne collection platform. By positioning laser range finding with the use of 1 second GPS with 200 Hz inertial measurement unit corrections; Terrapoint's LiDAR instruments are able to make highly detailed geospatial elevation products of the ground, man-made structures and vegetation.

The LiDAR ground extraction process takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance.

The purpose of this LiDAR data was to produce high accuracy 3D terrain geospatial products for Clay-Putnam Counties, Lot 2.

This report covers the mission parameter and details, processing step outlines and deliverables.

This report is submitted as a supporting overview document for the FGDC metadata reports that are included as an addendum to this report.

Acquisition

Parameter Overview

The Airborne LiDAR survey was conducted using two Optech 3100EA systems flying at a nominal height of 970 meters AGL with a total angular coverage of 18.1 degrees with a 4 degree cutoff. Flight line spacing was nominally 219.28 meters providing overlap of 55% on adjacent flight lines. Lines were flown in north/south and northwest/southeast orientated blocks to best optimize flying time considering the layout for the project. Three PA-31 Navajo aircraft, registrations C-GPJT, C-FEHB, and C-FQQB, were used for the survey. This aircrafts have a flight range of approximately 6 hours and was flown at an average altitude of 970 meters above ground level (AGL). The aircraft was staged from St. Augustine Airport (KSGJ), St. Augustine, Florida, and ferried daily to the project site for flight operations.

The Optech 3100EA system was configured in the following manner for the Clay-Putnam Counties, Lot 2:

Type of Scanner = Optech 3100EA
Data Acquisition Height = 970 meters AGL
Scanner Field of View = 18.1 degrees with a 4 degree cutoff
Scan Frequency = 55.2 Hertz
Pulse Repetition Rate = 100 Kilohertz
Aircraft Speed = 150 Knots
Swath Width = 487.29 m Nominal
Ground Sample Distance = 0.70 meters - no overlap
Number of Returns per Pulse = 4
Distance between Flight Lines = 219.28 m

GPS Receivers

A combination of Sokkia GSR 2600 and NovAtel DL-4+ dual frequency GPS receivers were used to support the airborne operations of this survey and to establish the GPS control network.

Missions Statistics

For the Clay-Putnam Counties, Lot 2, a total of 9 missions were flown for this project with good meteorological and GPS conditions. 237 flight lines were flown over the project site to provide complete coverage.

The LiDAR missions for the Clay-Putnam Counties, Lot 2, were carried out from September 6, 2007 and September 12, 2007.

Reference Coordinate System Used

Clay-Putnam Counties, Lot 2

Two existing NGS (National Geodetic Survey) monuments were observed in a GPS control network.
Existing monuments BC2493 and BC0251 were used as primary control for this project.

The published horizontal datum of the NGS stations is NAD83 HARN and the vertical datum NAVD88.

The following are the final coordinates of the newly established control points used in this project:

Station_ID: BC2493
West_Longitude: -81 54 21.88180
North_Latitude: 30 41 24.92680
Ellips_Elev: -11.1613

Station_ID: BC0251
West_Longitude: -81 38 50.59179
North_Latitude: 30 25 27.60406
Ellips_Elev: -21.136

Geoid Model Used

The Geoid03 geoid model, published by the NGS, was used to transform all ellipsoidal heights to orthometric.

Processing

Airborne GPS Kinematic

Airborne GPS kinematic data was processed on-site using GrafNav kinematic On-The-Fly (OTF) software. Flights were flown with a minimum of 6 satellites in view (13^0 above the horizon) and with a PDOP of better than 4.5. Distances from base station to aircraft were kept to a maximum of 30 km, to ensure a strong OTF (On-The-Fly) solution. For all flights, the GPS data can be classified as excellent, with GPS residuals of 5cm average but no larger than 9 cm being recorded.

Generation and Calibration of Laser Points (raw data)

Calibration is performed to eliminate systematic bias in the system, which would result in a bias in the data. By determining the bias they can then be modeled and the effects removed from the data. The manufacturer initially calibrates the system on manufacture. Subsequently each mission is checked and calibrated to ensure data quality.

Manufacturer Calibration

Manufacturer calibration was completed upon manufacture and upon delivery of the system to Terrapoint. The manufacturer maintains and calibrates each LiDAR system annually and upon any field visits to service the system.

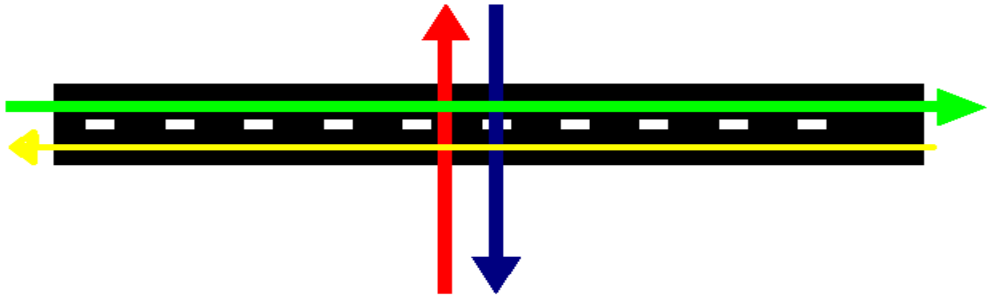
Manufacturer calibration addresses both radiometric and geometric calibration. Radiometric calibration is to ensure that the laser meets specification for pulse energy, width, and rise time, frequency and beam divergence. These values are tested by the manufacturer and annually certified. Radiometric calibration also checks the alignment between transmitter and receiver and assures that alignment is optimal.

Geometric calibration is also conducted by the manufacturer both in the laboratory and with onsite flights in previously surveyed areas. Range calibration determines the first/last range offsets. Scanner calibration provides values for scanner offset and scale. Position orientation alignment provides Pos misalignment angles.

The Following are the manufacturer derived calibration values that are constant unless the IMU is changed:

AltmSerialNo= 05Sen183
ImuType= LN200A1
ImuRate= 200
ScannerScale= 1.0064
ScannerOffset= -0.0171
FirstPulseRange= -2.76
SecondPulseRange= -2.76
ThirdPulseRange= -2.76
LastPulseRange= -2.76
IMURoll= 0.031
IMUPitch= -0.008
IMUHeading= 0.000
UserToImuEx= -0.020
UserToImuEy= 0.005
UserToImuEz= -0.150
UserToImuDx= -0.09
UserToImuDy= -0.008
UserToImuDz= -0.096
UserToRefDx= -0.051
UserToRefDy= -0.030
UserToRefDz= -0.488
TimeLag= 0.000012
IntensityGainFor3070= 20
UseDroopCorrection= 15.0

Field Calibration is used to determine the roll, pitch, heading and scanner scale values. This is essentially the same as bore-sighting. The roll pitch heading and scanner scale biases are determined by comparing overlapping and opposing flightlines. Each mission is flown to have two cross lines that intersect every flightline and these lines are used to determine the roll, pitch heading and scanner scale.



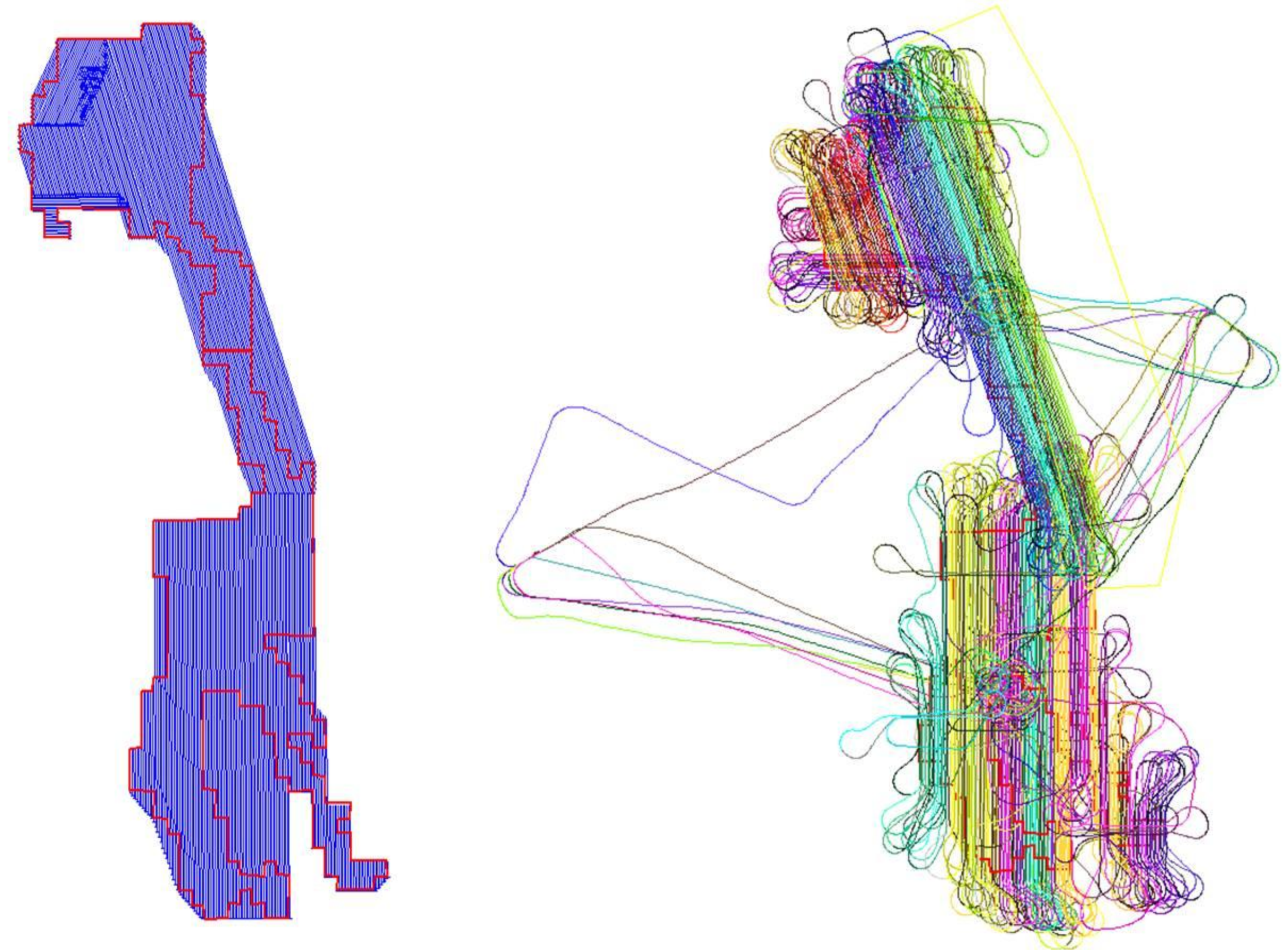


Figure 6 Example of mission flight-lines and mission trajectory showing cross lines used to determine calibration values

The mission data is initially output using the manufacturer calibration default values for the specific system. The data is then examined using a combination of Terrascan Terramodel and Terramatch and user input to determine the final roll, pitch, and heading and scanner scale. Once the values are finalized the mission data is output in LAS format.

Table 2: Control Point Comparison	
Average dz	-0.179

Minimum dz	-0.576
Maximum dz	+0.197
Average magnitude	0.218
Root mean square	0.257
Std deviation	0.194

The data is then checked against control data to ensure vertical accuracy. Each mission's data is based on the post-processed position of a base station. The base stations used were all tied into geodetic control points or were geodetic control points. Units are in US Survey Feet.

Because of this, the positional accuracy of the LiDAR data is ensured. The individual mission data can then be compared to adjoining missions to ensure both vertical and horizontal accuracy. If any offset either vertical of horizontal is found then the mission is reprocessed and checked for accuracy.

Vertical Bias Resolution

No D_z adjustments were made within this project.

Data Classification and Editing

The data was processed using the software Terrascan, and following the methodology described herein. The initial step is the setup of the Terrascan project, which is done by importing the Dewberry provided tile boundary index encompassing the entire project areas. The 3D laser point clouds, in binary format, were imported into the Terrascan project and divided in 3564 tiles for the Clay-Putnam Counties, Lot 2, in LAS 1.1 format. Once tiled, the laser points were classified using a proprietary routine in Terrascan. This routine removes any obvious outliers from the dataset following which the ground layer is extracted from the point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iteration. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model. The data is then manually quality controlled with the use of hillshading, cross-sections and profiles. Any points found to be of class vegetation, building or error during the quality control process, are removed from the ground model and placed on the appropriate layer. An integrity check is also performed simultaneously to verify that ground features such as rock cuts, elevated roads and crests are present. Once data has been cleaned and complete, it is then by a supervisor via manual inspection and through the use of a hillshade mosaic.

Deliverable Product Generation

Deliverable Tiling Scheme

All files were retiled in the provided tiling scheme with a total of 469 tiles for Clay-Putnam Counties, Lot 2.

LiDAR Point Data

The LiDAR point data was delivered in LAS 1.1 adhering to the following ASPRS classification scheme:

Class 1 – Unclassified
Class 2 – Ground
Class 7 – Noise
Class 9 – Water
Class 12 - Overlap

Water body delineation was collected using hillshades and intensity images generated from ground DEM and LiDAR.

The LAS files contain the following fields of information (Precision reported in brackets):

Class (Integer)
GPS Week Time (0.0001 seconds)
Easting (0.01 meter)
Northing (0.01 meter)
Elevation (0.01 meter)
Echo Number (Integer 1 to 4)
Echo (Integer 1 to 4)
Intensity (8 Bit Integer)
Flightline (Integer)
Scan Angle (Integer Degree)

Please note that the LiDAR intensity is not calibrated or normalized. The intensity value is meant to provide relative signal return strengths for features imaged by the sensor.

Point data was clipped to the project boundary.

FGDC Report

Separate metadata FGDC reports were delivered for the Clay-Putnam Counties, Lot 2. The reports are included as an addendum to this report.

Quality Control

Quality Control for Data Acquisition

A daily calibration flight is key to the QC process since it helps identify any systematic issues in data acquisition or failures on the part of the GPS, IMU or other equipment that may not have been evident to the LiDAR operator during the mission. The aircraft initially performs a figure-8 manoeuvre over the selected calibration site to collect calibration data for use in post-processing. The calibration site is ideally selected in a relatively open, tree-less area where several large buildings are located. The buildings used for calibration are surveyed using both GPS and conventional survey methods. A local network of GPS points are established to provide a baseline for conventional traversing around the perimeter of the buildings.

Ground truth validation is used to assess the data quality and consistency over sample areas of the project. To facilitate a confident evaluation, existing survey control is used to validate the LiDAR data. Published survey control, where the orthometric height (elevation) has been determined by precise differential levelling observation, is deemed to be suitable.

Ground truth validation points may be collected for each of the any terrain categories that Dewberry requires to establish RMSE accuracies for the LIDAR project. These points must be gathered in flat or uniformly sloped terrain (<20% slope) away from surface features such as stream banks, bridges or embankments. If collected, these points will be used during data processing to test the $RMSE_z$ accuracy of the final LiDAR data products.

The LiDAR operator performs kinematic post-processing of the aircraft GPS data in conjunction with the data collected at the Reference Station in closest proximity to the area flown. Double difference phase processing of the GPS data is used to achieve the greatest accuracy. The GPS position accuracy is assessed by comparison of forward and reverse processing solutions and a review of the computational statistics. Any data anomalies are identified and the necessary corrective actions are implemented prior to the next mission.

The quality control of LIDAR data and data products has proven to be a key concern by Dewberry. Many specifications detail how to measure the quality of LiDAR data given RMSE statistical methods to a 95% confidence level. In order to assure meeting all levels of QC concerns, Terrapoint has quality control and assurance steps in both the data acquisition phase and the data processing phase. Any acquired data sets that fail these checks are flagged for re-acquisition.

QC Step 1 - The Data Acquisition (DAQ) software performs automatic system and subsystem tests on power-up to verify proper functionality of the entire data acquisition system. Any anomalies are immediately investigated and corrected by the LiDAR operator if possible. Any persistent problems are referred to the engineering staff, which can usually resolve the issue by telephone and/or email. In the unlikely event that these steps do not resolve the problem, a trained engineer is immediately dispatched to the project site with the appropriate test equipment and spare parts needed to repair the system.

<u>QC Step 2</u> - The DAQ software continuously monitors the health and performance of all subsystems. Any anomalies are recorded in the System Log and reported to the LiDAR operator for resolution. If the operator is unable to correct the problem, the engineering staffs are immediately notified. They provide the operator with instructions or on-site assistance as needed to resolve the problem.

The DAQ software also provides real-time terrain viewers that allow the operator to directly monitor the data quality. Multiple returns from individual laser shots are color coded to provide the operator with an indication of the degree of penetration through dense vegetation. If any aspect of the data does not appear to be acceptable, the operator will review system settings to determine if an adjustment could improve the data quality. Navigation aids are provided to alert both the pilot and operator to any line following errors that could potentially compromise the data integrity. The pilot and operator review the data and determine whether an immediate re-flight of the line is required.

<u>QC Step 3</u> - After the mission is completed, raw LiDAR data on the removable disk drive is transferred to the Field PC at the field operations staging area. An automated QA/QC program scans the System Log as well as the raw data files to detect potential errors. Any problems identified are reported to the operator for further analysis. Data is also retrieved from all GPS Reference Stations, which were active during the mission and transferred to the Field PC. The GPS data is processed and tested for internal consistency and overall quality. Any errors or limit violations are reported to the operator for more detailed evaluation.

<u>QC Step 4</u> - The operators utilize a data viewer installed on the Field PC to review selected portions of the acquired LiDAR data. This permits a more thorough and detailed analysis than is possible in real-time during data collection. Corrupted files or problems in the data itself are noted. If the data indicates improper settings or operation of the LiDAR sensor, the operator determines the appropriate corrective actions needed prior to the next mission.

<u>QC Step 5</u> - All LiDAR and GPS data is copied from the Field PC onto Hard Drives: one for transfer to data processing, and one for local backup. Each Hard drive is reviewed to ensure data completeness and readability.

Quality Control for Data Processing

Quality assurance and quality control procedures for the raw LiDAR data and processed deliverables for the DEM and DTM products are performed in an iterative fashion through the entire data processing cycle. All final products pass through a seven-step QC control check to verify that the data meets the criteria specified by Dewberry.

Terrapoint has developed a rigorous and complete process, which does everything possible to ensure data will meet or exceed the technical specifications. Experience dealing with all ranges of difficulty in all types of topographic regions has led to the development of our quality assurance methods. Our goal is to confidently deliver a final product to Dewberry that is as precise as possible, the first time. Terrapoint will go to extraordinary lengths to make our customer completely satisfied. The following list provides a step-by-step explanation of the process used by Terrapoint to review the data prior to customer delivery.

<u>QC Step 1</u> - Data collected by the LiDAR unit is reviewed for completeness and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database. At this time, the data will be confirmed to have been acquired using instrumentation that records first and last returns for each laser pulse, or multiple returns per laser pulse.

<u>QC Step 2</u> - The LiDAR data is post processed and calibrated for as a preliminary step for product delivery. At this time, the data are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. Flight line swath overlap will be confirmed to have adjacent flight lines at the tolerance specified by Dewberry for overlap throughout the project area thus enabling an evaluation of data reproducibility throughout the areas.

<u>QC Step3</u> - The full-featured product is reviewed as a grid and as raw points and attention is placed on locating and eliminating any outlier or anomalous points beyond three-sigma values. These points may be spikes, unusually high points, or pits, unusually low points. LiDAR points returning from low clouds, birds, pollution, or noise in the system can cause spikes. Pit-like low returns can come from water features or damp soils or from system noise. Either type of point needs to be classified as an error point and eliminated from use by any grid products. In addition to these outliers, the full-feature product is reviewed for NO DATA points and regular looking non-surface errors like scan lines appearing

in the data. Also, steps between flight lines are measured and adjusted as needed.

Unusual or odd-looking features and questionable returns are checked for validity and compared against additional source material such as aerial photos, USGS digital maps, local maps, or by field inspection. Most errors found at this QC step can be resolved by re-calibration of the data set or by eliminating specific problem points.

<u>QC Step 4</u> - After the full-feature data is at a clean stage, all points are classified as ground and unclassified features. Any non-regular structures or features like radio towers, large rock outcrops, water bodies, bridges, piers, are confirmed to be classified into the category specified by Dewberry for these feature types. Additional data sets like commercially available data sources or data sources provided by Dewberry may be used to assist and verify that points are assigned into correct classifications.

<u>QC Step 5</u> - After the full-featured data set is certified as passing for completeness and for the removal of outliers, attention may be shifted to quality controlling the bare-earth model. This product may take several iterations to create it to the quality level that Dewberry is looking for. As both Terrapoint and Dewberry inspect the bare-earth model, adjustments are made to fine-tune and fix specific errors.

Adjustments to the bare-earth model are generally made to fix errors created by over-mowing the data set along mountaintops, shorelines, or other areas of high percent slope. Also, vegetation artefacts leave a signature surface that appears bumpy or rough. Every effort is made to remove spurious vegetation values and remnants from the bare-earth model. All adjustments are made by re-classifying points from ground to unclassified or vice versa. No adjustments are made to the final grid product, as other parties cannot easily reproduce these types of adjustments from the original, raw data set.

<u>QC Step 6</u> - Both $RMSE_z$ and $RMSE_{xy}$ are inspected in the classified bare-earth model and compared to project specifications. $RMSE_z$ is examined in open, flat areas away from breaks and under specified vegetation categories. Neither $RMSE_z$ nor $RMSE_{xy}$ are compared to orthoimagery or existing building footprints. Comparison against imagery can skew the determination of accuracy because of the lean and shadows in the imagery.

Instead, a point to point comparison of a recently acquired or existing high confidence ground survey point to its nearest neighbour LiDAR laser return point. This is done in the raw data set and usually with Terrascan software. The tolerance for finding a near-by LiDAR point elevation to compare to a survey point elevation is that the two points must be within a 0.5m radius of each other in open flat areas is made. If no LiDAR points can be found within in this tolerance, then alternative methodologies are used to convert the LiDAR to a TIN, though this can introduce biases and processing errors in the end products and could cause the RMSE values to be skewed and fall beyond project specifications.

QC Step 7 - A final QC step is made against all deliverables before they are sent to Dewberry. The deliverables are checked for file naming convention, integrity checks of the files, conformance to file format requirements, delivery media readability, and file size limits. In addition, as data are delivered all requested reports would be delivered as they become available.

Positional Accuracy

Vertical Positional Accuracy

The elevation data was verified internally prior to delivery to Dewberry to ensure it met fundamental accuracy requirements when compared kinematic to Terrapoint GPS checkpoints. Below is the summary for the three sites.

- The LiDAR dataset for Clay-Putnam Counties, Lot 2, was tested 0.087m vertical accuracy at 95 percent confidence level, based on consolidated $RMSE_z$ (0.035m) x 1.9600.

Horizontal Positional Accuracy

Compiled to meet 1 meter horizontal accuracy at the 95 percent confidence level.

Figure 2 Example of Control pts (flightline 1) loaded with the raw data to check vertical accuracy

Conclusion

Overall the LiDAR data products submitted to Dewberry meet and exceed both the absolute and relative accuracy requirements set out in the task order for this project. The quality control requirements required in Terrapoint's IPROVE program were adhered to throughout the project cycle to ensure product quality.

IDENTIFICATION_INFORMATION

Citation:
Citation_Information:
Originator: Terrapoint USA
Publication_Date: 20081031
Title: Dewberry FDEM Clay Putnam Counties Task Order 20070525-4927 Contract No. 07-HS-34-14-00-22-469

Geospatial_Data_Presentation_Form: Map
Online_Linkage: none
Larger_Work_Citation:
Citation_Information:
Originator: Terrapoint USA
Publication_Date: 20081031
Title: Dewberry Dewberry FDEM Clay Putnam Counties Contract No. 2007-150-U
Publication_Information:
Publication_Place: Houston, Texas
Publisher: Terrapoint USA
Online_Linkage: none
Description:
Abstract:
LIDAR data is remotely sensed high-resolution elevation data collected by an airborne collection platform. By positioning laser range finding with the use of 1 second GPS with 100hz inertial measurement unit corrections; Terrapoint's LIDAR instruments are able to make highly detailed geospatial elevation products of the ground, man-made structures and vegetation. The LiDAR flightlines for this project was planned for a 50% acquisition overlap. The nominal resolution of this project without overlap is 1.25m. Four returns were recorded for each pulse in addition to an intensity value. GPS Week Time, Intensity, Flightline and number attributes were provided for each LiDAR point.
Data is provided as random points, in LAS v1.1 format, classified in following code list 1=Unclassified 2=Ground 7=Noise 9=Water 12=Overlap

Purpose:
The purpose of this LiDAR data was to produce high accuracy 3D elevation based geospatial products for mapping.

Supplemental_Information:
LiDAR Collection Specific Supplemental Information:

- General Overview:
The Airborne LiDAR survey was conducted using 1 OPTECH 3100EA system flying at a nominal height of 970m AGL with a total angular coverage of 18.1 degrees with a 4 degree cutoff. Flight line spacing was nominally 219.28m providing overlap of 55% on adjacent flight lines. Lines were flown in north/south and northwest/southeast orientated blocks to best optimize flying time considering the layout for the project.

The total project size is 1089 square kilometers

The aircrafts were PA-31 Navajos, registration C-FEHB, C-FQQB,and C-GPJT, that were used for the survey. This aircraft has a flight range of approximately 6 hours and was flown at an average altitude of 970 meters above sea level (ASL). The aircraft was staged from the TLH Airport, Tallahassee Regional Airport, Tallahassee, Florida, and ferried daily to the project site for flight operations.

Aircraft Speed = 150 Knots
Number of Scanners = 2
Swath Width 487.29m Nominal
Distance Between Flight Lines = 219.28m
Data Acquisition Height = 970 meters AGL
Pulse Repetition Rate = 100 kHz
Number of Returns Per Pulse = 4
Scanner Field Of View = +/- 18.1 degrees
Scan Frequency = 55.2 Hertz

- GPS Receivers

A combination of Sokkia GSR 2600 and NovAtel DL-4+ dual frequency GPS receivers were used to support the airborne operations of this survey and to establish the GPS control network.

- Number of Flights and Flight Lines

A total of 9 missions and 237 flightlines were flown for this project with flight times ranging approximately 6 hours under good meteorological and GPS conditions.

- Reference Coordinate System Used:

Existing monuments BC2493 and BC0251 were used to control all flight missions and kinematic ground surveys.

The published horizontal datum of the NGS stations is NAD83 HARN and the vertical datum NAVD88. The following are the final coordinates of the newly established control points used in this project:

Station_ID: BC2493
West_Longitude: -81 54 21.88180
North_Latitude: 30 41 24.92680
Ellips_Elev: -11.1613
Station_ID: BC0251
West_Longitude: -81 38 50.59179
North_Latitude: 30 25 27.60406
Ellips_Elev: -21.136

- Geoid Model Used
The Geoid03 geoid model, published by the NGS, was used to transform all ellipsoidal heights to orthometric.

-General LiDAR notes

-Intensity
Please note that the LiDAR intensity is not calibrated or normalized. The intensity value is meant to provide relative signal return strengths for features imaged by the sensor.

-Waterbodies
Water is not included in the bare earth ground points for lakes, rather it is classified as water on Class 9. Water body delineation was collected using hillshades and intensity images generated from ground DEM and LiDAR.

Time_Period_of_Content:
  Time_Period_Information:
    Range_of_Dates/Times:
      Beginning_Date: 20070906
      Ending_Date: 20080211
  Currentness_Reference: Ground Condition
Status:
  Progress: Complete
  Maintenance_and_Update_Frequency: None planned
Spatial_Domain:
  Bounding_Coordinates:
    West_Bounding_Coordinate: -81.90
    East_Bounding_Coordinate: -81.42
    North_Bounding_Coordinate: 30.20
    South_Bounding_Coordinate: 29.33
Keywords:
  Theme:
    Theme_Keyword_Thesaurus: None
    Theme_Keyword: ASPRS standards
    Theme_Keyword: DEM
    Theme_Keyword: digital elevation model
    Theme_Keyword: elevation
    Theme_Keyword: LAS_v1.1
    Theme_Keyword: laser
    Theme_Keyword: LiDAR
    Theme_Keyword: OPTECH_3100EA
    Theme_Keyword: surface model
  Place:

Place_Keyword_Thesaurus: None
Place_Keyword: clay/Putnam Counties
Place_Keyword: Florida
Place_Keyword: United States of America
Place_Keyword: Southeast

Access_Constraints:
All deliverable data and documentation shall be free from restrictions regarding use and distribution. Data and documentation provided under this task order shall be freely distributable by government agencies.
Use_Constraints:
Any conclusions from results of the analysis of this LiDAR are not the responsibility of Terrapoint. The LiDAR data was thoroughly visually verified to represent the true ground conditions at time of collection. Users should be aware of this limitations of this dataset if using for critical applications.
Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Florida DEM
Contact_Address:
Address_Type: mailing and physical address
Address: 2555 Shumard Oak Boulevard
City: Tallahassee
State_or_Province: FL
Postal_Code: 32399-2100
Country: USA
Contact_Voice_Telephone: 850-413-9907
Contact_Facsimile_Telephone: 850-488-1016
Contact_Electronic_Mail_Address: gis@dca.state.fl.us

DATA_QUALITY_INFORMATION

Attribute_Accuracy:
Attribute_Accuracy_Report:
Raw elevation measurements have been tested to 0.257 US Survey Ft for vertical accuracy at 95 percent confidence level

Logical_Consistency_Report:
All LiDAR files delivered were verified and tested to ensure they open and are positioned properly.
Completeness_Report:
According to Terrapoint standards; the following aspects of the LiDAR data was verified during the course of the

project processing:
-Data completeness and integrity
-Data accuracy and errors
-Anomaly checks through full-feature hillshades
-Post automated classification Bare-earth verification
-RMSE inspection of final bare-earth model using kinematic GPS
-Final quality control of deliverable products; ensuring integrity; graphical quality; conformance to Terrapoint standards are met for all delivered products.
-Special note for this dataset: On a project level, a coverage check is carried out to ensure no slivers are present; however due to resale nature of this task order and the desire to maximize coverage, some minor slivers were detected and reported to the client via polygon shape files. The slivers were reflown and filled.

Positional_Accuracy:
  Horizontal_Positional_Accuracy:
    Horizontal_Positional_Accuracy_Report:
      Compiled to meet 1 meter horizontal accuracy at the 95 percent confidence level
  Vertical_Positional_Accuracy:
    Vertical_Positional_Accuracy_Report:
      Tested to 0.286 US Survey Ft.
Lineage:
  Source_Information:
    Source_Citation:
      Citation_Information:
        Originator: Terrapoint USA
        Publication_Date: 20080903
        Title: Dewberry FDEM Clay Putnam Counties
        Edition: One
        Geospatial_Data_Presentation_Form: map
        Publication_Information:
          Publication_Place: Houston, Texas
          Publisher: Terrapoint USA
        Online_Linkage: www.terrapoint.com
        Larger_Work_Citation:
          Citation_Information:
            Originator: Terrapoint USA
            Publication_Date: 20080903
            Title: Dewberry FDEM Clay/Putnam Counties
            Publication_Information:
              Publication_Place: Houston, Texas
              Publisher: Terrapoint USA
            Online_Linkage: www.terrapoint.com
    Type_of_Source_Media: Hard Drive

Source_Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 20070906
Ending_Date: 20080813
Source_Currentness_Reference: Ground Condition
Source_Citation_Abbreviation: none
Source_Contribution: none

Process_Step:
Process_Description:
- Airborne GPS Kinematic
Airborne GPS kinematic data was processed on-site using GrafNav kinematic On-The-Fly (OTF) software. Flights were flown with a minimum of 6 satellites in view (13o above the horizon) and with a PDOP of better than 4.5. Distances from base station to aircraft were kept to a maximum of 30 km, to ensure a strong OTF (On-The-Fly) solution. For all flights, the GPS data can be classified as excellent, with GPS residuals of 5cm average but no larger than 9 cm being recorded.
Source_Used_Citation_Abbreviation: GPS Processing
Process_Date: 200710
Source_Produced_Citation_Abbreviation: GPS
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Organization: Terrapoint USA
Contact_Person: Peggy Cobb
Contact_Position: Production Manager
Contact_Address:
Address_Type: mailing and physical address
Address: 251216 Grogan's Park Drive
City: The Woodlands
State_or_Province: Texas
Postal_Code: 77380
Country: USA
Contact_Voice_Telephone: 1-877-999-7687
Contact_Facsimile_Telephone: 1-281-296-0869
Contact_Electronic_Mail_Address: peggy.cobb@terrapoint.com
Hours_of_Service: Monday to Friday, 8 - 5, CST
Process_Step:
Process_Description:
- Generation and Calibration of laser points (raw data)
The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes

and compile any data if not complete.
Subsequently the mission points are output using Optech's Dashmap, initially with default values from Optech or the last mission calibrated for system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality. All missions are validated against the adjoining missions for relative vertical biases and collected GPS kinematic ground truthing points for absolute vertical accuracy purposes.
On a project level, a coverage check is carried out to ensure no slivers are present.

Source_Used_Citation_Abbreviation: Calibration
Process_Date: 200710
Source_Produced_Citation_Abbreviation: CAL
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Organization: Terrapoint USA
Contact_Person: Peggy Cobb
Contact_Position: Production Manager
Contact_Address:
Address_Type: mailing and physical address
Address: 251216 Grogan's Park Drive
City: The Woodlands
State_or_Province: Texas
Postal_Code: 77380
Country: USA
Contact_Voice_Telephone: 1-877-999-7687
Contact_Facsimile_Telephone: 1-281-296-0869
Contact_Electronic_Mail_Address: peggy.cobb@terrapoint.com
Hours_of_Service: Monday to Friday, 8 - 5, CST
Process_Step:
Process_Description:
- Vertical Bias Resolution
Due to limitations in the Optech Dashmap software, the following Dz adjustments were adjusted post calibration manually in Terrascan to the following missions to ensure they tie to adjoining missions and GPS kinematic validation points:
System;Year;Mission;Delta_Z_Adjustment_(cm): No adjustments were done.
Source_Used_Citation_Abbreviation: Vertical Bias Resolution
Process_Date: 200710
Source_Produced_Citation_Abbreviation: Dz
Process_Contact:

Contact_Information:
Contact_Person_Primary:
Contact_Organization: Terrapoint USA
Contact_Person: Peggy Cobb
Contact_Position: Production Manager
Contact_Address:
Address_Type: mailing and physical address
Address: 251216 Grogan's Park Drive
City: The Woodlands
State_or_Province: Texas
Postal_Code: 77380
Country: USA
Contact_Voice_Telephone: 1-877-999-7687
Contact_Facsimile_Telephone: 1-281-296-0869
Contact_Electronic_Mail_Address: peggy.cobb@terrapoint.com
Hours_of_Service: Monday to Friday, 8 - 5, CST
Process_Step:
Process_Description:
- Data Classification and Editing
The data was processed using the software TerraScan, and following the methodology described herein. The initial step is the setup of the TerraScan project, which is done by importing client provided tile boundary index encompassing the entire project areas. The 3D laser point clouds, in binary format, were imported into the TerraScan project and divided in 469 tiles.
Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine removes any obvious outliers from the dataset following which the ground layer is extracted from the point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within an iteration.
A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model. The data is then manually quality controlled with the use of hillshading,

cross-sections and profiles. Any points found
to be of class vegetation, building or error during the
quality control process, are removed from the ground model
and placed on the appropriate layer. An integrity check is
also performed simultaneously to verify that ground
features such as rock cuts, elevated roads and crests are
present. Once data has been cleaned and complete, it is then
reviewed by a supervisor via manual inspection and through
the use of a hillshade mosaic of the entire project area.
Source_Used_Citation_Abbreviation: Processing
Process_Date: 20080813
Source_Produced_Citation_Abbreviation: PRD
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Organization: Terrapoint USA
Contact_Person: Peggy Cobb
Contact_Position: Production Manager
Contact_Address:
Address_Type: mailing and physical address
Address: 251216 Grogan's Park Drive
City: The Woodlands
State_or_Province: Texas
Postal_Code: 77380
Country: USA
Contact_Voice_Telephone: 1-877-999-7687
Contact_Facsimile_Telephone: 1-281-296-0869
Contact_Electronic_Mail_Address: peggy.cobb@terrapoint.com
Hours_of_Service: Monday to Friday, 8 - 5, CST
Process_Step:
Process_Description:
-Deliverable Product Generation
>LiDAR Point Data
The LiDAR point data was delivered in LAS 1.0 adhering to the following ASPRS classification scheme:
Class 1 - Non-ground; Class 2 - Ground; Class 7 - Noise; Class 9 - Water
The LAS files contain the following fields of information (Precision reported in brackets):
Class (Integer); GPS Week Time (0.0001 seconds); Easting (0.01 meter); Northing (0.01 meter);
Elevation (0.01 meter); Echo Number (Integer 1 to 4); Echo (Integer 1 to 4); Intensity (8 Bit Integer);
Flightline (Integer); Scan Angle (Integer Degree)
Point data was clipped to the project boundary.
Water body delineation was collected using hillshades
and intensity images generated from ground DEM and LiDAR.
>FGDC Report

Source_Used_Citation_Abbreviation: Processing_Deliverables
Process_Date: 20080407
Source_Produced_Citation_Abbreviation: PRD_DEL
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Organization: Terrapoint USA
Contact_Person: Peggy Cobb
Contact_Position: Production Manager
Contact_Address:
Address_Type: mailing and physical address
Address: 251216 Grogan's Park Drive
City: The Woodlands
State_or_Province: Texas
Postal_Code: 77380
Country: USA
Contact_Voice_Telephone: 1-877-999-7687
Contact_Facsimile_Telephone: 1-281-296-0869
Contact_Electronic_Mail_Address: peggy.cobb@terrapoint.com
Hours_of_Service: Monday to Friday, 8 - 5, CST

SPATIAL_REFERENCE_INFORMATION

Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 0901
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.9999
Longitude_of_Central_Meridian: -81
Latitude_of_Projection_Origin: 30
False_Easting: 600000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: Coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.01
Ordinate_Resolution: 0.01
Planar_Distance_Units: US Survey Feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983 HARN
Ellipsoid_Name: GRS 80
Semi-major_Axis: 6378137.0000000
Denominator_of_Flattening_Ratio: 298.26

Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name: North American Vertical Datum of 1988
Altitude_Resolution: 0.01
Altitude_Distance_Units: US Survey Feet
Altitude_Encoding_Method: Explicit elevation coordinate included with horizontal coordinates

ENTITY_AND_ATTRIBUTE_INFORMATION

Overview_Description:
Entity_and_Attribute_Overview:
Original LiDAR point data in LAS 1.0, all deliverables in LAS binary 1.1. The LAS binary files contain the following fields of information (Precision reported in brackets):
Easting (0.01 meter); Northing (0.01 meter); Elevation (0.01 meter); Class (Integer); Description; Flightline; Timestamp; Echo (return); Intensity; Scan Angle; Echo number
Entity_and_Attribute_Detail_Citation: none

DISTRIBUTION_INFORMATION

Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Florida Division of Emergency Management
Contact_Address:
Address_Type: mailing and physical address
Address: 2555 Shumard Oak Blvd
City: Tallahassee
State_or_Province: FL
Postal_Code: 32399
Country: USA
Contact_Voice_Telephone: 850-413-9907
Contact_Facsimile_Telephone: 850-488-1016
Contact_Electronic_Mail_Address: EOC-GIS@em.myflorida.com
Resource_Description:
The LiDAR data was captured for Dewberry for
Proposed flood mapping purposes
Distribution_Liability:
Users must assume responsibilty to determine the
appropriate use of this LiDAR dataset.

Data is representative of ground conditions at time of
acquisition only.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:

Format_Name:LAS binary
Digital_Transfer_Option:
Offline_Option:
Offline_Media: Harddrive
Recording_Format: Windows Compatible
Compatibility_Information: Windows Compatible
Fees: Current Handling and Processing Terrapoint Fees
Ordering_Instructions:
Proper release required from Dewberry for
orders outside of Dewberry. Please contact Terrapoint
sales for general Terrapoint LiDAR library sales.

METADATA_REFERENCE_INFORMATION

Metadata_Date: 20081031
Metadata_Review_Date: 20081031
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Richard Butgereit
Contact_Organization: Florida DEM
Contact_Position: GIS Administrator
Contact_Address:
Address_Type: mailing and physical address
Address: 2555 Shumard Oak Boulevard
City: Tallahassee
State_or_Province: FL
Postal_Code: 32399-2100
Country: USA
Contact_Voice_Telephone: 850-413-9907
Contact_Facsimile_Telephone: 850-488-1016
Contact_Electronic_Mail_Address: richard.butgereit@em.myflorida.com
Metadata_Standard_Name: FGDC CSDGM
Metadata_Standard_Version: FGDC-STD-001-1998

Appendix E: QA/QC Checkpoints and Discrepancies

Point Number		Land Cover Class	SPCS NAD83/99 North Zone Easting-X (Ft)	Northing-Y (Ft)	NAVD88 Survey-Z (Ft)	LIDAR-Z	ΔZ
* CL01-1	1	BE & Low Grass	486152.97	1868713.18	10.90	12.01	1.11
CL02-1	1	BE & Low Grass	508888.22	1835102.17	3.22	3.00	-0.23
CL03-1	1	BE & Low Grass	493936.54	1887536.88	16.01	15.69	-0.32
CL04-1	1	BE & Low Grass	468160.49	1908522.14	7.90	7.35	-0.55
CL05-1	1	BE & Low Grass	456722.35	1835490.21	9.96	10.03	0.07
CL06-1	1	BE & Low Grass	421165.57	1869457.01	14.19	13.67	-0.52
* CL07-1	1	BE & Low Grass	425756.98	1903566.16	25.52	24.71	-0.81
CL08-1	1	BE & Low Grass	429242.43	1942699.98	13.70	13.62	-0.08
CL09-1	1	BE & Low Grass	448136.66	1958765.85	25.53	25.96	0.43
* CL10-1	1	BE & Low Grass	486151.74	1953909.06	8.35	N/A	N/A
CL11-1	1	BE & Low Grass	460341.28	2008008.95	8.70	8.82	0.12
CL12-1	1	BE & Low Grass	456646.72	1933037.28	11.48	11.64	0.16
CL13-1	1	BE & Low Grass	477883.54	1928335.62	25.12	24.91	-0.21
CL14-1	1	BE & Low Grass	470387.56	1959198.27	14.82	14.98	0.16
CL15-1	1	BE & Low Grass	473280.72	1976748.85	13.79	13.90	0.11
CL16-1	1	BE & Low Grass	485914.55	1971449.91	2.37	2.60	0.23
CL17-1	1	BE & Low Grass	444209.82	1893289.82	84.59	84.34	-0.25
CL18-1	1	BE & Low Grass	449707.46	2032135.01	14.42	14.34	-0.08
CL19-1	1	BE & Low Grass	445641.97	2054966.65	9.28	9.03	-0.25
CL20-1	1	BE & Low Grass	436143.62	2103260.23	8.19	8.09	-0.10
CL21-1	1	BE & Low Grass	432799.68	2130903.74	22.07	21.78	-0.29
CL22-1	1	BE & Low Grass	409988.90	2097103.64	13.31	13.27	-0.04
CL23-1	1	BE & Low Grass	388131.67	2094564.40	27.24	26.91	-0.33
CL24-1	1	BE & Low Grass	428697.16	2071190.75	22.37	21.86	-0.51
CL25-1	1	BE & Low Grass	430598.20	2119853.38	6.94	7.15	0.21
* CL01-2	2	Brush & Low Trees	486168.68	1868879.00	6.89	9.63	2.74
CL02-2	2	Brush & Low Trees	509079.84	1835125.03	3.02	2.83	-0.19
CL03-2	2	Brush & Low Trees	493925.57	1887498.21	16.59	16.93	0.34
CL04-2	2	Brush & Low Trees	468236.39	1908391.38	9.56	8.90	-0.66
CL05-2	2	Brush & Low Trees	456874.35	1835573.98	12.45	12.35	-0.10
CL06-2	2	Brush & Low Trees	421085.29	1869555.49	14.78	14.67	-0.11
CL07-2	2	Brush & Low Trees	425814.78	1903671.31	25.24	25.12	-0.12
CL08-2	2	Brush & Low Trees	429208.92	1942572.84	13.51	13.68	0.17
CL09-2	2	Brush & Low Trees	447937.09	1958592.95	25.88	26.48	0.60
CL10-2	2	Brush & Low Trees	486121.41	1953803.26	6.84	7.93	1.09
CL11-2	2	Brush & Low Trees	460257.63	2007867.12	7.41	8.45	1.04
CL12-2	2	Brush & Low Trees	456654.03	1932921.65	11.62	11.68	0.06
CL13-2	2	Brush & Low Trees	477845.41	1928201.25	24.15	24.33	0.18
CL14-2	2	Brush & Low Trees	470411.89	1958927.00	15.39	16.23	0.84
CL15-2	2	Brush & Low Trees	473434.02	1976685.89	13.25	13.80	0.55
CL16-2	2	Brush & Low Trees	486019.90	1971296.30	2.78	2.36	-0.42
CL17-2	2	Brush & Low Trees	444309.56	1893427.49	86.32	86.47	0.15
CL18-2	2	Brush & Low Trees	449839.91	2031916.92	15.45	16.04	0.59
CL19-2	2	Brush & Low Trees	445527.69	2055173.78	7.36	7.46	0.10
CL20-2	2	Brush & Low Trees	436328.85	2102968.21	8.36	8.35	-0.01
CL21-2	2	Brush & Low Trees	433062.95	2131167.36	21.93	22.18	0.25
CL22-2	2	Brush & Low Trees	410153.85	2097113.23	12.84	12.79	-0.05
CL23-2	2	Brush & Low Trees	388273.54	2094660.41	26.20	26.22	0.02
CL24-2	2	Brush & Low Trees	428573.30	2071227.85	20.03	19.85	-0.18
CL25-2	2	Brush & Low Trees	430517.60	2119681.78	5.07	5.25	0.18
* CL01-3	3	Forested	486260.97	1868812.62	7.72	9.68	1.96

* CL02-3	3	Forested	509079.69	1835085.94	3.66	2.42	-1.25
CL03-3	3	Forested	494010.85	1887623.13	16.90	16.35	-0.56
CL04-3	3	Forested	468165.20	1908373.96	11.29	10.44	-0.85
CL05-3	3	Forested	457120.10	1835583.07	12.68	13.16	0.48
CL06-3	3	Forested	420903.17	1869549.57	14.50	13.67	-0.83
CL07-3	3	Forested	425661.64	1903421.17	24.40	25.25	0.85
CL08-3	3	Forested	429090.02	1942557.44	13.34	13.48	0.14
CL09-3	3	Forested	448125.72	1959043.11	24.86	25.59	0.73
CL10-3	3	Forested	486076.95	1953778.62	5.70	6.91	1.21
CL11-3	3	Forested	460353.11	2007885.39	9.07	9.65	0.57
CL12-3	3	Forested	456830.48	1933035.73	6.30	6.13	-0.17
CL13-3	3	Forested	477926.58	1928380.65	24.18	23.92	-0.26
CL14-3	3	Forested	470644.34	1958957.02	14.44	14.96	0.52
CL15-3	3	Forested	473084.20	1976849.78	13.04	13.52	0.48
CL16-4	3	Forested	485939.98	1971318.64	3.89	3.19	-0.70
CL17-3	3	Forested	444254.14	1893415.42	86.17	86.22	0.05
CL18-3	3	Forested	449622.39	2031957.40	15.71	15.47	-0.24
CL19-3	3	Forested	445754.74	2054869.09	11.28	11.52	0.24
CL20-3	3	Forested	436169.80	2103334.37	7.07	7.55	0.48
CL21-3	3	Forested	432673.75	2131135.93	21.90	21.38	-0.52
CL22-3	3	Forested	410008.66	2096981.94	13.97	13.51	-0.47
CL23-3	3	Forested	387982.74	2094882.90	26.32	25.69	-0.63
CL24-3	3	Forested	428601.60	2071180.02	20.22	19.80	-0.42
CL25-3	3	Forested	430668.70	2119760.18	10.59	11.10	0.51
CL01-4	4	Urban	486099.41	1868699.13	12.61	13.63	1.02
CL02-4	4	Urban	508893.91	1835048.48	4.88	4.62	-0.26
CL03-4	4	Urban	494002.93	1887517.95	18.21	17.31	-0.91
CL04-4	4	Urban	468112.85	1908448.91	9.47	8.87	-0.60
CL05-4	4	Urban	456748.68	1835537.31	12.24	12.05	-0.19
CL06-4	4	Urban	420989.41	1869447.16	10.26	9.51	-0.75
CL08-4	4	Urban	429391.72	1942508.69	13.00	12.87	-0.13
CL09-4	4	Urban	448196.20	1958858.52	26.29	26.26	-0.03
CL10-4	4	Urban	485982.60	1953845.13	9.39	10.09	0.70
CL11-4	4	Urban	460267.14	2007911.00	10.72	11.05	0.32
CL12-4	4	Urban	456578.34	1933021.65	10.35	9.96	-0.39
CL13-4	4	Urban	477877.37	1928264.82	26.07	25.49	-0.58
CL14-4	4	Urban	470498.88	1958914.60	15.28	15.08	-0.20
CL15-4	4	Urban	473256.69	1976847.31	14.32	14.51	0.19
CL16-5	4	Urban	485837.23	1971407.79	3.44	3.02	-0.42
CL17-4	4	Urban	444200.10	1893340.44	86.37	86.46	0.08
CL18-4	4	Urban	449635.02	2032078.92	15.90	15.69	-0.21
CL19-4	4	Urban	445919.17	2054995.47	10.85	10.68	-0.17
CL20-4	4	Urban	436027.21	2103210.36	8.10	7.65	-0.45
CL21-4	4	Urban	432810.98	2130816.75	24.50	24.21	-0.29
CL22-4	4	Urban	409962.30	2097311.76	12.71	12.48	-0.23
CL23-4	4	Urban	388047.82	2094707.72	29.08	28.55	-0.53
CL24-4	4	Urban	428845.10	2071268.38	22.32	21.89	-0.43
CL25-4	4	Urban	430453.73	2119709.73	9.07	9.03	-0.04

Points too close to uneven ground to yield accurate TIN surface elevations and were not used						
Point No	**Land Cover Class**		**Survey - Z**	**ΔZ**	**ΔZ*2**	**ABS ΔZ**
CL01-1	1	BE & Low Grass	10.9	1.109	1.23	1.11
CL07-1	1	BE & Low Grass	25.52	-0.807	0.65	0.81
CL10-1	1	BE & Low Grass	8.35	N/A	N/A	N/A
CL01-2	2	Brush & Low Trees	6.89	2.739	7.50	2.74
CL01-3	3	Forested	7.72	1.964	3.86	1.96
CL02-3	3	Forested	3.66	-1.245	1.55	1.25

100 % of Totals	# of Points	RMSE (ft) Spec = 0.61 (BE = 0.30)	Mean (ft)	Median (ft)	Min (ft)	Max (ft)
Consolidated	93	0.46	-0.02	-0.08	-0.91	1.21
BE & Low Grass	22	0.28	-0.10	-0.09	-0.55	0.43
Brush & Low Trees	24	0.46	0.18	0.13	-0.66	1.09
Forested	23	0.58	0.03	0.05	-0.85	1.21
Urban	24	0.46	-0.19	-0.22	-0.91	1.02

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Consolidated	93		0.87	
BE & Low Grass	22	0.55		0.52
Brush & Low Trees	24			1.01
Forested	23			0.85
Urban	24			0.88

Appendix F: LiDAR Vertical Accuracy Report

Vertical Accuracy Assessment Report
2007 LiDAR Bare-Earth Dataset for
Clay-Putnam Counties, Florida

Date: August 8, 2008

References: A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a
B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003
D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Background
FDEM Guidance: Reference A tasked PDS to validate the bare-earth LiDAR dataset of Clay-Putnam Counties, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the vertical accuracy assessment only, for which FDEM's major specifications are summarized as follows:

- Vertical accuracy: $\leq$ 0.30 feet $RMSE_z$ = $\leq$ 0.60 feet vertical accuracy at 95% confidence level, tested in flat, non-vegetated terrain only, employing NSSDA procedures in Reference B.
- Validation that the data also satisfies FEMA requirements in Reference C.
- Vertical units (orthometric heights) are in US Survey Feet, NAVD88.

NSSDA Guidance: Section 3.2.2 of Reference B specifies: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

FEMA Guidance: Section A.8.6 of Reference C specifies the following LiDAR testing requirement for data to be used by the National Flood Insurance Program (NFIP): "For the NFIP, TINs (and DEMs derived there from) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied … The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following: [followed by explanations of seven potential categories]… Ground cover Categories 1 through 5 are fairly common everywhere … The assigned Mapping Partner shall select a minimum of 20 test points for each major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on."

Note: for this project PDS followed the FDEM guidelines in Reference A, which stipulates that the vertical accuracy report will be based on a minimum of 30 ground measurements for each of four land cover categories, totaling 120 test points for each 500 square mile area of new topographic data collection. Note the area covered in Clay-Putnam Counties contained 464 tiles and there is an average of 30 checkpoints established in each land cover category. The land cover measurements distributed through each project area will be collected for each of the following land cover categories:

1. Bare-earth and low grass
2. Brush Lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

NDEP and ASPRS Guidance: NDEP guidelines (Reference D) and ASPRS guidelines (Reference E) also recommend a minimum of 60 checkpoints, with up to 100 points preferred. (These guidelines are referenced because FEMA's next update to Appendix A will include these newer NDEP and ASPRS guidelines, now recognizing that vertical errors for LiDAR bare-earth datasets in vegetated terrain do not necessarily follow a normal error distribution as assumed by the NSSDA.)

Vertical Accuracy Test Procedures

Ground Truth Surveys: The PDS team established a primary geodetic network covering approximately 6,000 square miles along the panhandle area of Northwest Florida to provide accurate and consistent control throughout the project area, which includes Clay-Putnam Counties. The Primary Network was used to establish base stations to support airborne GPS data acquisition. Two Secondary control networks were established to support the measurement of checkpoints used in the accuracy validation process for newly generated LiDAR and Orthophotography.

Assessment Procedures and Results: The LiDAR accuracy assessment for Clay-Putnam Counties was performed in accordance with References D and E which assume that LiDAR errors in some land cover categories may not follow a normal error distribution. This assessment was also performed in accordance with References B and C which assume that LiDAR bare-earth datasets errors do follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in Clay-Putnam Counties' four major land cover categories: (1) bare-earth and low grass, (2) brush lands and low trees, (3) forested areas fully covered by trees, (4) urban areas. When a LiDAR bare-earth dataset passes testing by both methods, compared with criteria specified in Reference A, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for FDEM and FEMA requirements.

The relevant testing criteria, as stipulated in Reference A is summarized in Table 1.

Table 1 — DTM Acceptance Criteria for Clay-Putnam Counties

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	0.60 ft (0.30 ft $RMSE_z$ x 1.96000) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	1.19 ft (based on 95th percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References D and E specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). FVA determines how well the LiDAR sensor performed in category (1), open terrain, where errors are random and normally distributed; whereas SVA determines how well the vegetation classification algorithms worked in land cover categories (2) and (3) where LiDAR elevations are often higher than surveyed elevations and category (4) where LiDAR elevations are often lower.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600, as specified in Reference B. For Clay-Putnam Counties, for which floodplains are essentially flat, FDEM required the FVA to be 0.60 ft (18.29 cm) at the 95% confidence level (based on an $RMSE_z$ of 0.30 ft (9.14 cm), equivalent to 1 ft contours).

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. FDEM's CVA standard is 1.19 ft at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, brush lands and low trees, forested areas, and urban areas, in order to facilitate the analysis of the data based on each of these land cover categories that exist within Clay-Putnam Counties. The SVA criteria in Table 1 (1.19 ft at the 95% confidence level for each category) are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy FEMA's mandatory CVA criterion.

QA/QC Steps: The primary QA/QC steps used by PDS were as follows:

1. PDS surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of "cluster areas" where PDS attempted to survey a minimum of 25 QA/QC checkpoints in each of the four land cover categories. Some clusters may not include points from all cover categories. The final totals were 25 checkpoints in bare-earth and low grass; 25 checkpoints in brush and low trees; 25 checkpoints in forested areas; and 25checkpoints in urban areas, for a total of 100 checkpoints.
2. Next, PDS interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 100 checkpoints.
3. PDS then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values using procedures in References D and E.

4. The data were analyzed by PDS to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by FDEM guidelines. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

Figure 1 shows the location of the QA/QC checkpoint clusters within Clay-Putnam Counties. Each point represents a checkpoint cluster. There are nominally four checkpoints in each cluster, one per land cover category.

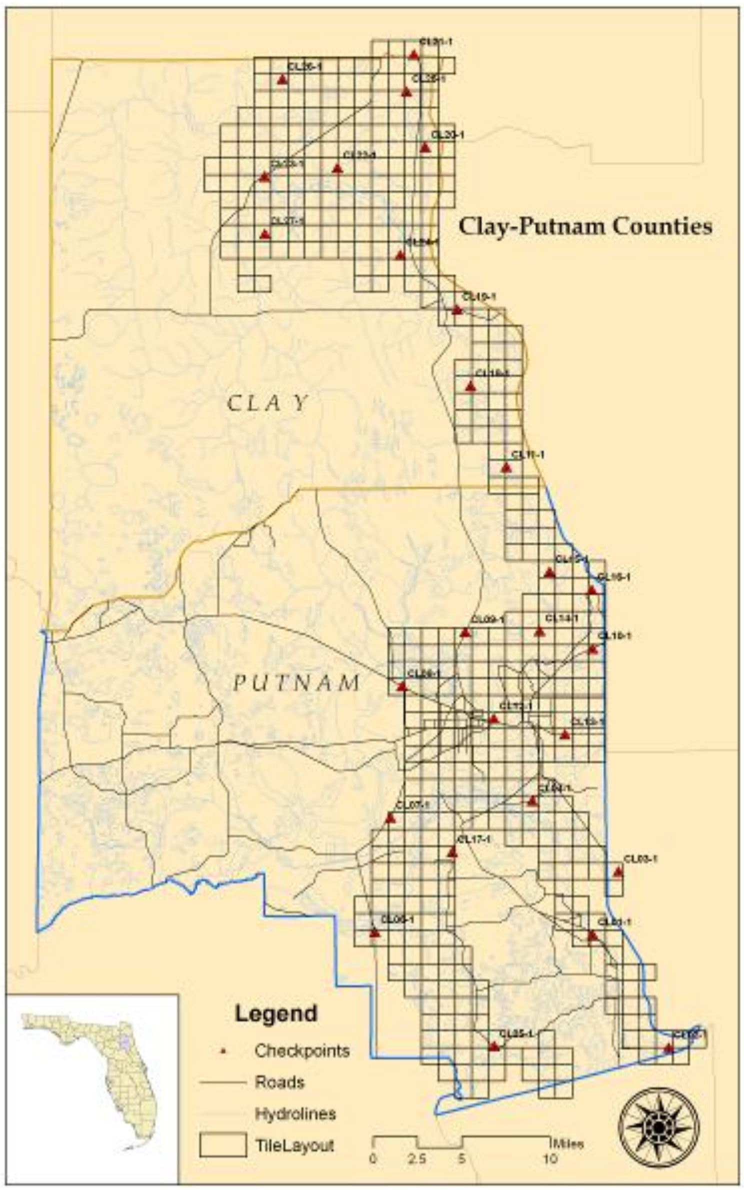


Figure 1 — Location of QA/QC Checkpoint Clusters for Clay-Putnam Counties

Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95^{th} Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95^{th} Percentile) Target = 1.19 ft
Total Combined	93		0.87	
BE & Low Grass	22	0.55		0.52
Brush & Low Trees	24			1.01
Forested	23			0.85
Urban	24			0.88

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NDEP/ASPRS methodology:

The $RMSE_z$ in bare-earth and low grass was within the target criteria of 0.30 ft, and the FVA tested 0.55 ft at the 95% confidence level in open terrain, based on $RMSE_z$ x 1.9600.

Compared with the 1.19 ft specification, CVA tested 0.87 ft at the 95% confidence level in bare-earth and low grass, brush and low trees, forested, and urban areas combined, based on the 95th Percentile. Table 3 lists the 5% outliers larger than the 95^{th} percentile error; whereas 5% of the points could have exceeded the 1.19 ft criterion, only one point actually exceeded this criterion.

Table 3 — 5% Outliers Larger than 95th Percentile

<table>
<tr><th>Land Cover Category</th><th>Elevation Diff. (ft)</th><td rowspan="8">Only one point (CL10-3) exceeded the 1.19 ft 95^{th} percentile criteria by 0.02’</td></tr>
<tr><td>Forested</td><td>1.21</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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</table>

Compared with the 1.19 ft SVA target values, SVA tested 0..42 ft at the 95% confidence level in bare-earth and low grass; 1.01 ft in brush and low trees; 0.85 ft in forested areas; and 0.88 ft in urban areas, based on the 95th Percentile. Each of the four land cover categories were well within the target value of 1.19 ft.

Figure 2 illustrates the SVA by specific land cover category.

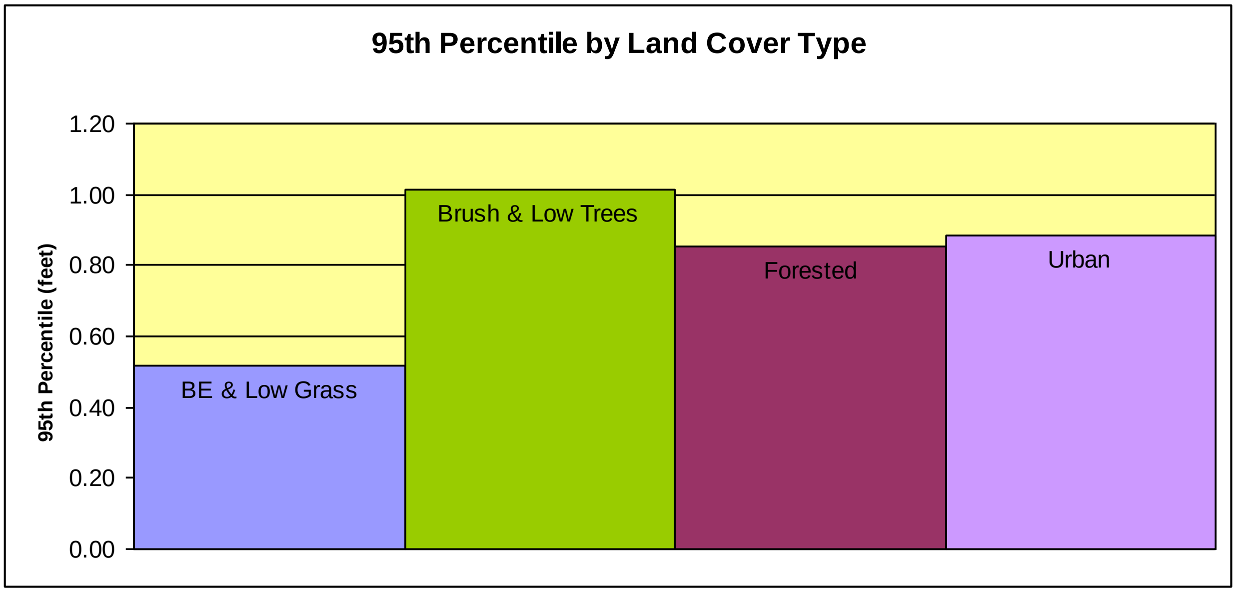

Figure 2 — Graph of SVA Values by Land Cover

Figure 3 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest. This shows a fairly normal distribution of points in all land cover classifications.

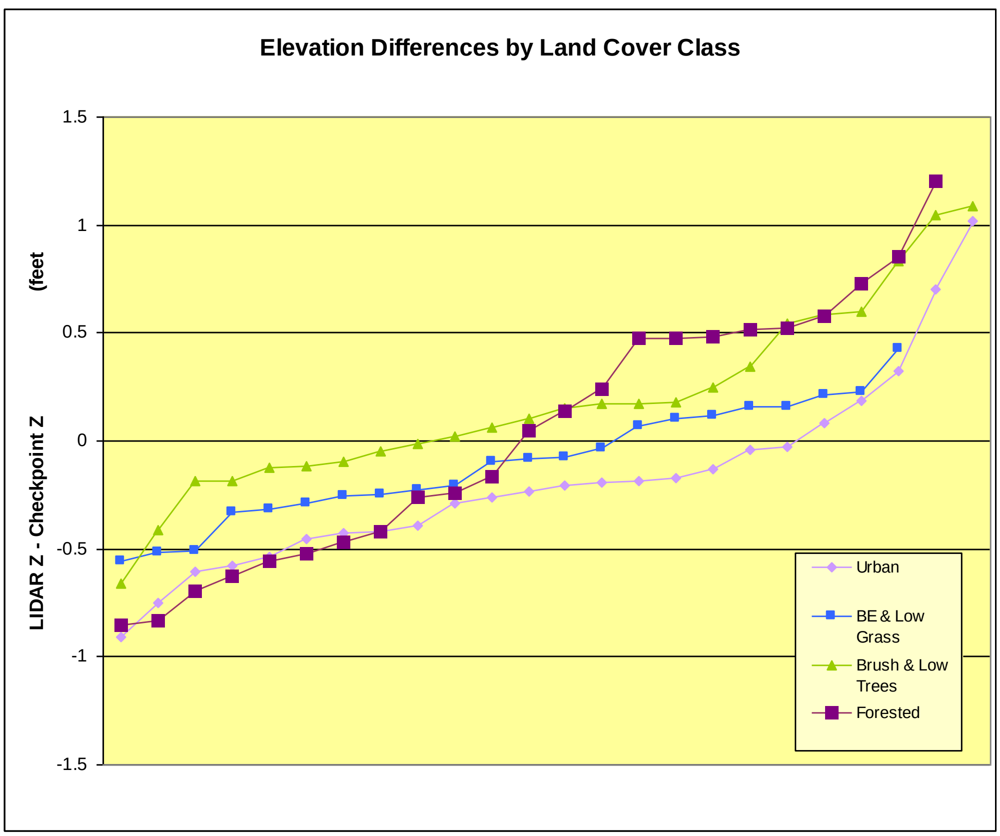

Figure 3 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

The NSSDA and FEMA guidelines were both published before it was recognized that LiDAR errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, $RMSE_z$ statistics were computed in all four land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the LiDAR data. These statistics are summarized in Figures 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference C.

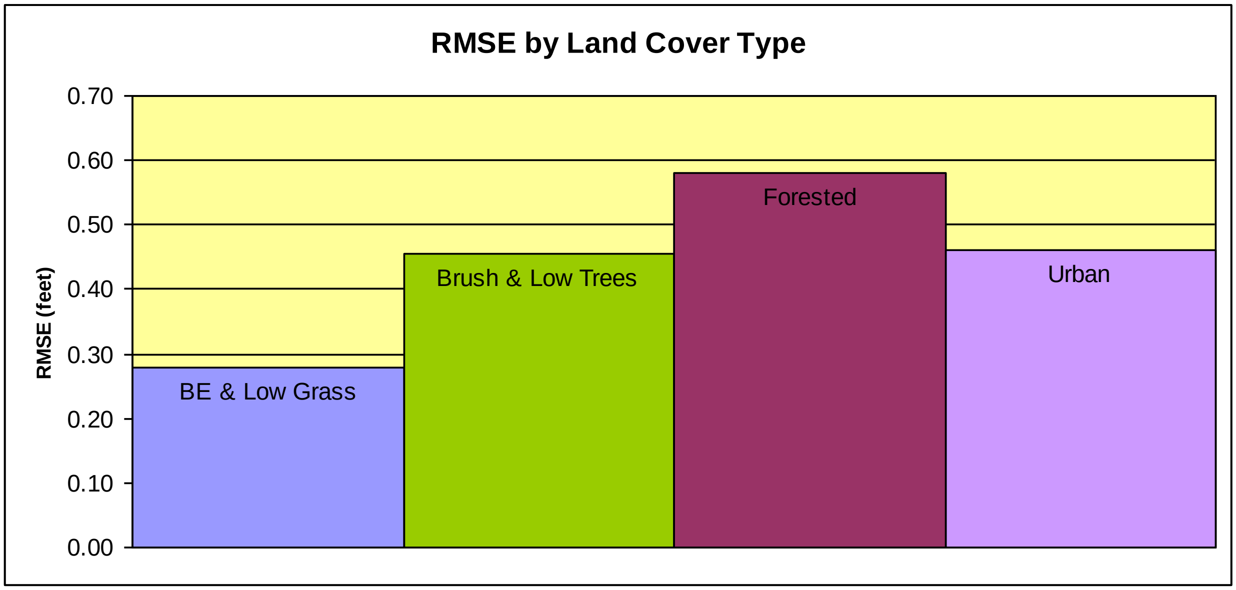

Figure 4 — $RMSE_z$ statistics by Land Cover Category

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

Descriptive Statistics							
Land Cover Category	**Points**	**RMSE (feet)**	**Mean Error (feet)**	**Median Error (feet)**	**SKEW**	**STDEV (feet)**	**95th Percentile (feet)**
Consolidated	93	0.46	-0.02	-0.08	0.52	0.46	0.87
BE & Low Grass	22	0.28	-0.10	-0.09	0.03	0.27	0.52
Brush & Low Trees	24	0.46	0.18	0.13	0.53	0.43	1.01
Forested	23	0.58	0.03	0.05	0.15	0.59	0.85
Urban	24	0.46	-0.19	-0.22	1.11	0.43	0.88

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NSSDA/FEMA methodology:

Although the NSSDA and FEMA guidelines predated FVA and CVA terminology, vertical accuracy at the 95% confidence level (called $Accuracy_z$) is computed by the formula $RMSE_z$ x 1.9600. $Accuracy_z$ in open terrain = 0.28 ft x 1.9600 = 0.55 ft, satisfying the 0.60 ft FVA standard. $Accuracy_z$ in consolidated categories = 0.46 ft x 1.9600 = 0.90 ft, satisfying the 1.19 ft CVA standard.

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.91 ft and a high of +1.21 ft, the histogram shows that the majority of the discrepancies are slightly skewed on the positive side of what would be a "bell curve," with mean of zero, if the data were truly normally distributed. Typically the discrepancies tend to skew a bit more to the positive side, because discrepancies in vegetation are typically positive.

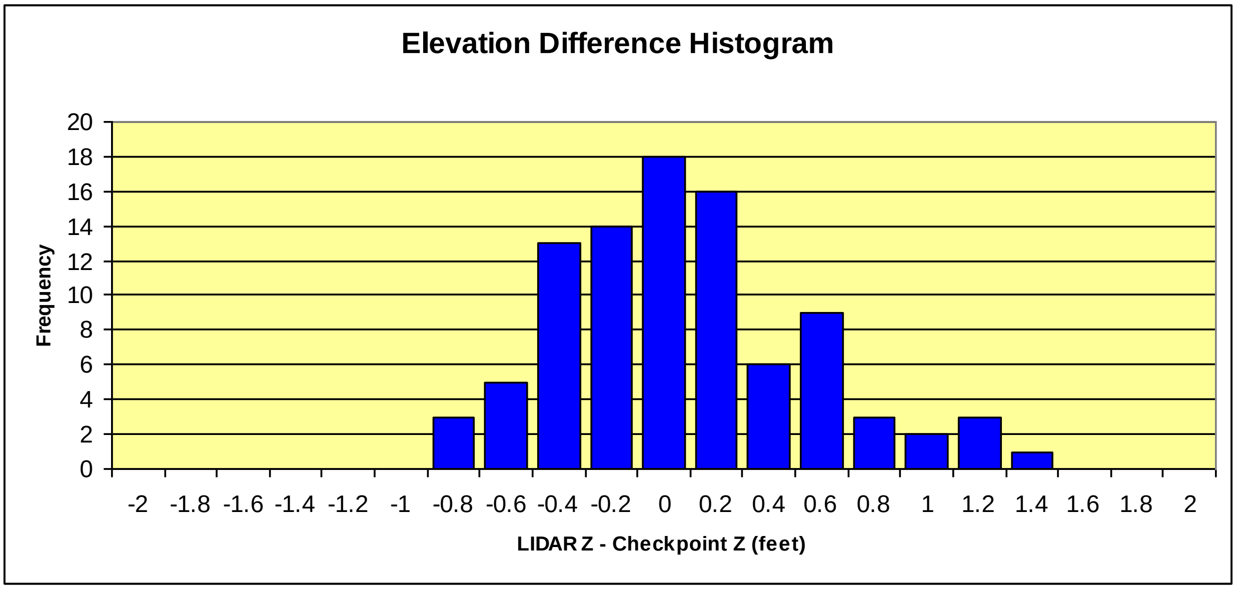

Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Checkpoints That Were Not Used

As indicated in table 4 below from Appendix E, a total of 6 points were not used in the vertical accuracy assessment due to placement on or very near uneven ground.

Points too close to uneven ground to yield accurate TIN surface elevations and were not used						
Point No	**Land Cover Class**		**Survey - Z**	**ΔZ**	**ΔZ*2**	**ABS ΔZ**
CL01-1	1	BE & Low Grass	10.9	1.109	1.23	1.11
CL07-1	1	BE & Low Grass	25.52	-0.807	0.65	0.81
CL10-1	1	BE & Low Grass	8.35	N/A	N/A	N/A
CL01-2	2	Brush & Low Trees	6.89	2.739	7.50	2.74
CL01-3	3	Forested	7.72	1.964	3.86	1.96
CL02-3	3	Forested	3.66	-1.245	1.55	1.25

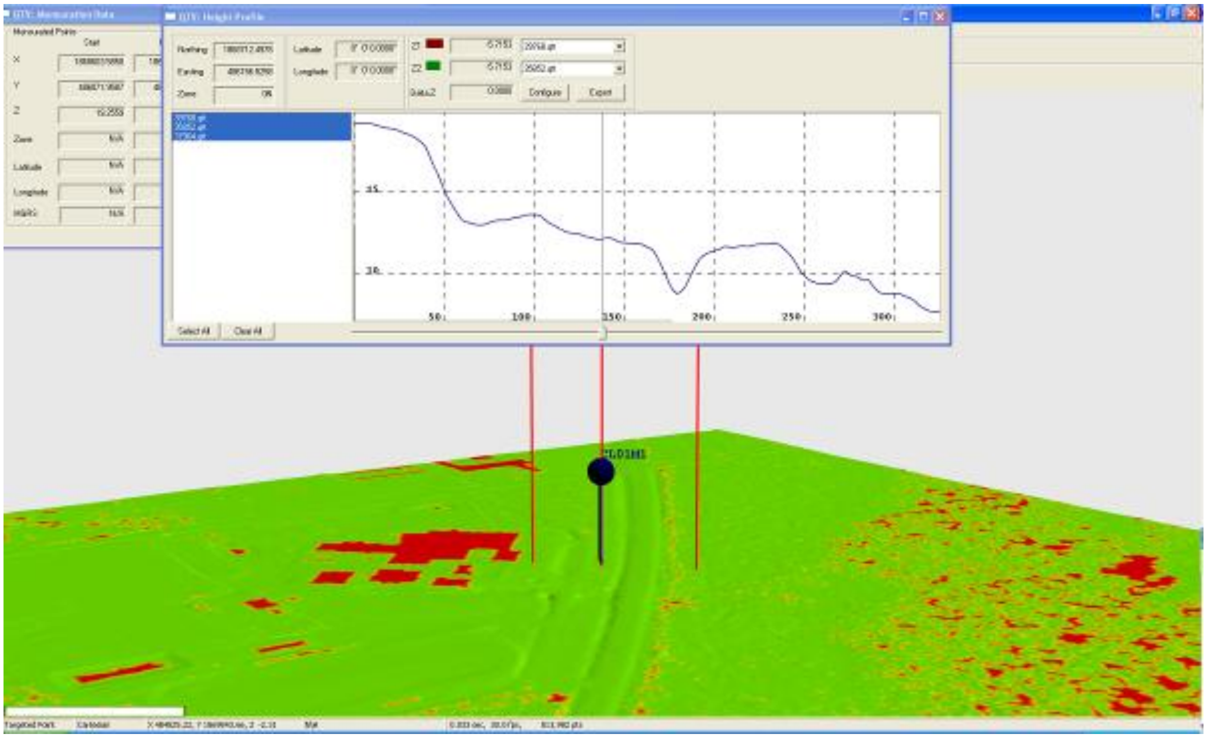

Figure 6 — Checkpoint CL01-1, CAT 1, uneven terrain, not used in the vertical accuracy assessment

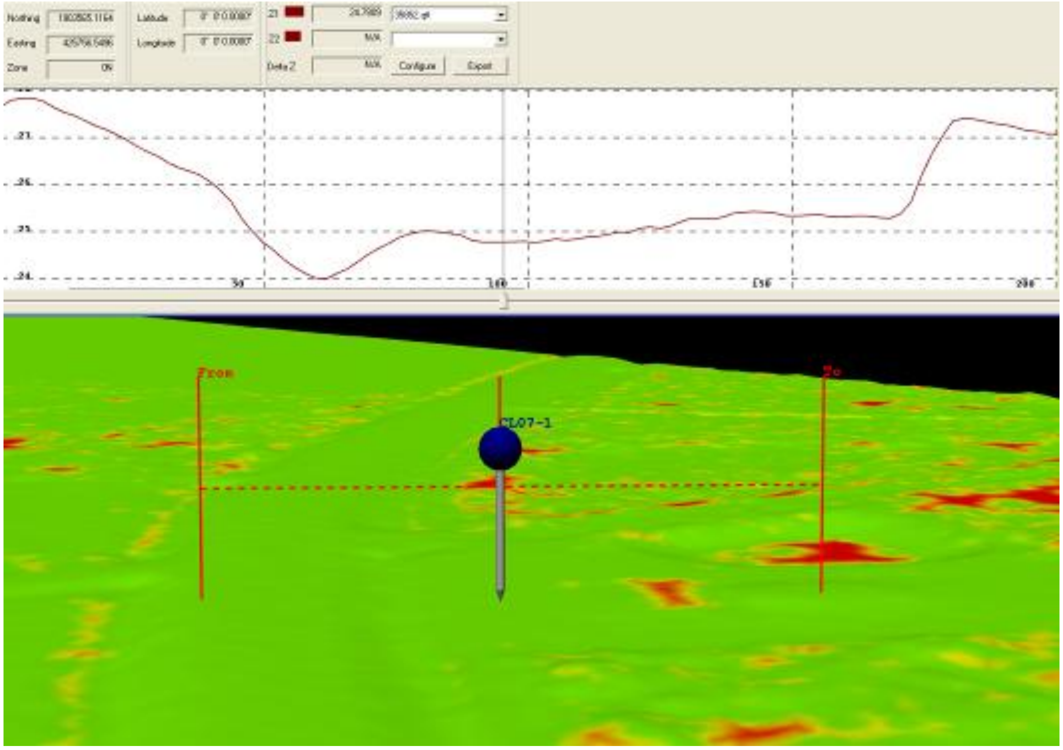

Figure 7 – Checkpoint CL07-1, CAT 1, uneven terrain, not used in the vertical accuracy assessment

Figure 8 – Checkpoint CL10-1, CAT 1, photo shows point located over top of large box culvert

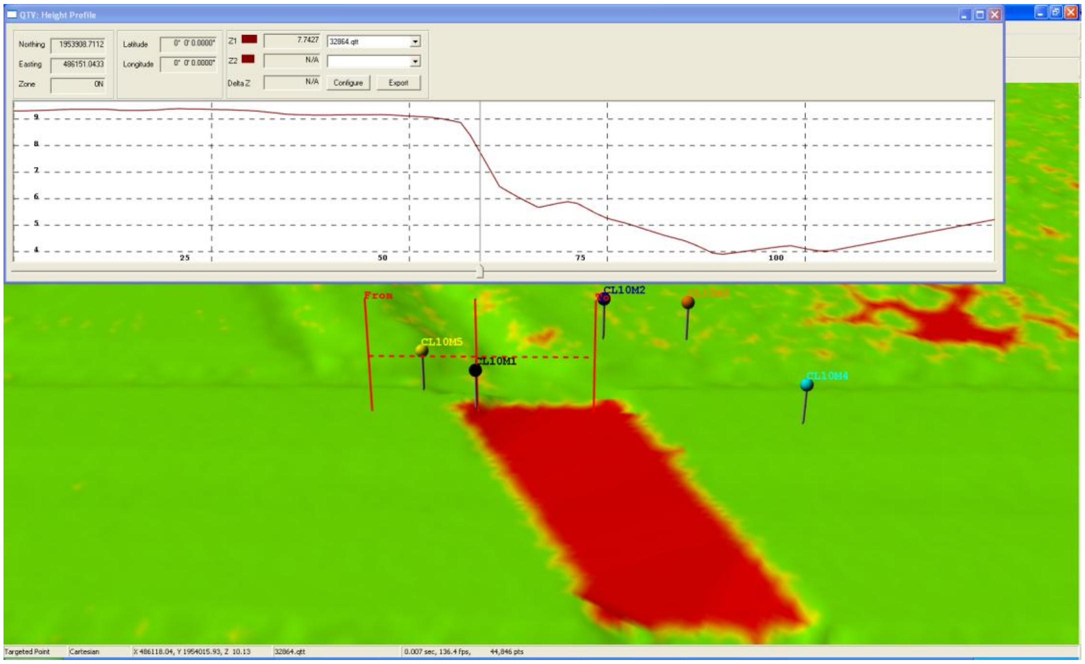

Figure 9 – Checkpoint CL10-1, CAT 1, ground point above culvert removed and reclassified; unable to determine accurate bare-earth surface elevation – point was not used in the accuracy assessment

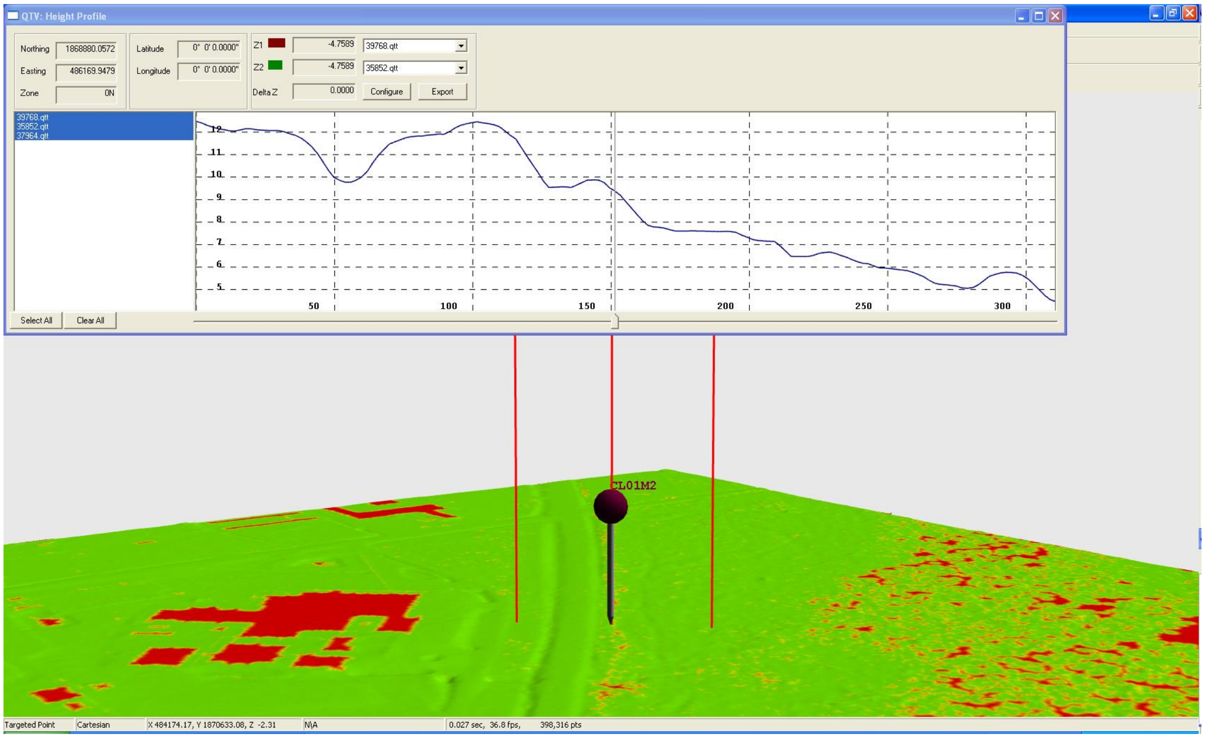

Figure 10 – Checkpoint CL01-2, CAT 2, uneven terrain, not used in the vertical accuracy assessment

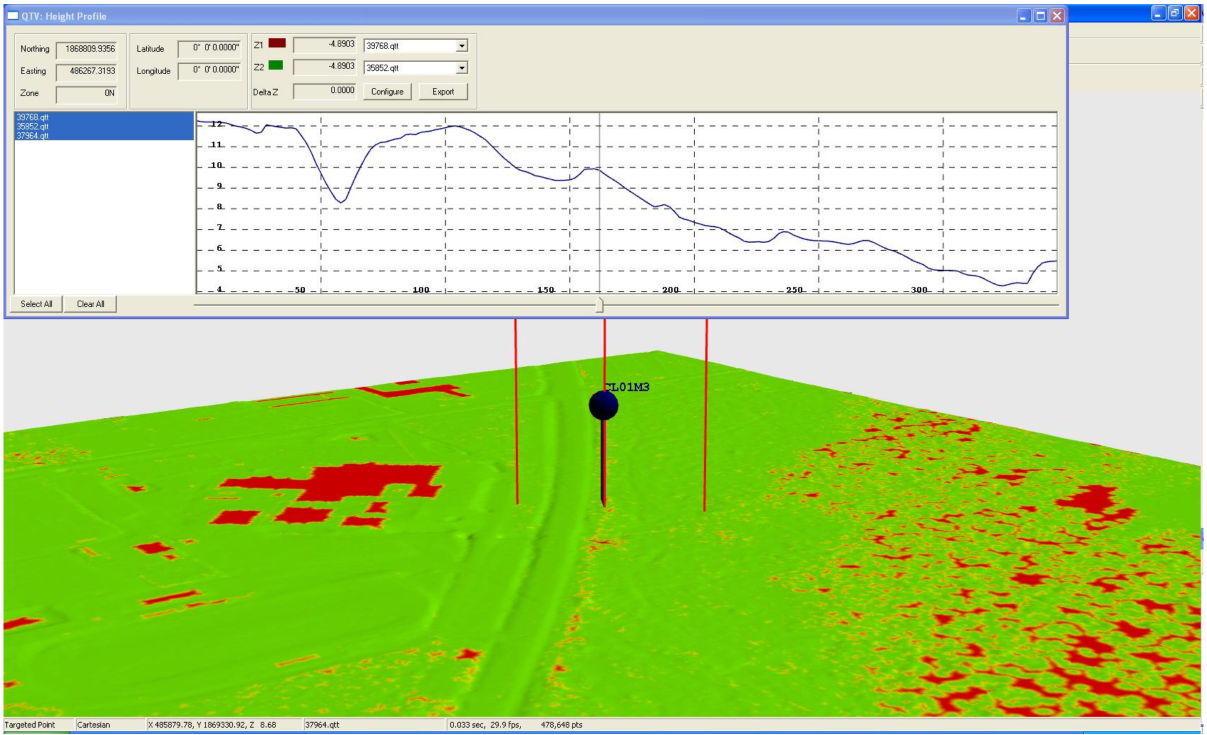

Figure 11 – Checkpoint CL01-3, CAT 3, uneven terrain, not used in the vertical accuracy assessment

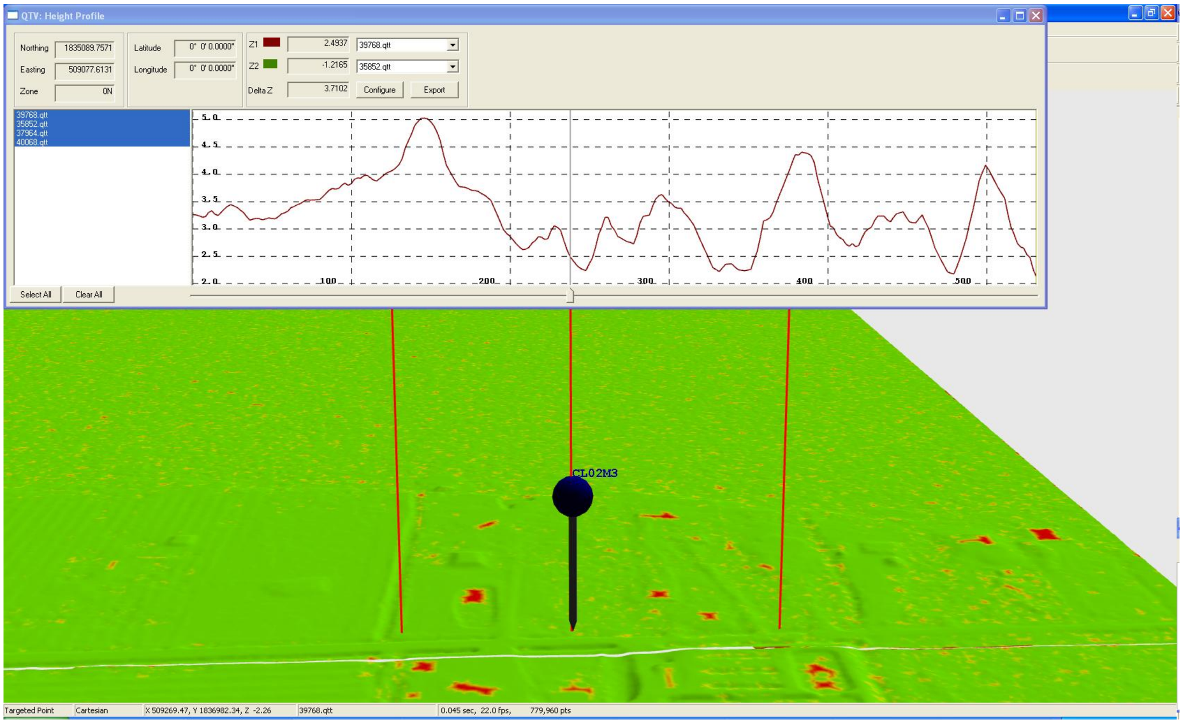

Figure 12 – Checkpoint CL02-3, CAT 3, uneven terrain, not used in the vertical accuracy assessment

Conclusions

Based on the vertical accuracy testing conducted by PDS, the undersigned certifies that the LiDAR dataset for Clay-Putnam Counties, Florida satisfies the criteria established by Reference A:

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.55' vertical accuracy at 95% confidence level in open terrain.**

- **Based on NSSDA and FEMA methodology: Tested 0.87' vertical accuracy at 95% confidence level in all land cover categories combined.**

David F. Maune, Ph.D., PSM, PS, GS, CP
QA/QC Manager

Appendix G: LiDAR Qualitative Assessment Report

References:

A ─ State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a

B ─ Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, “Geospatial Positioning Accuracy Standards,” published by the Federal Geographic Data Committee (FGDC), 1998

C ─ Appendix A, *Guidance for Aerial Mapping and Surveying*, “Guidelines and Specifications for Flood Hazard Mapping Partners,” published by the Federal Emergency Management Agency (FEMA), April 2003

D ─ *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004

E ─ *ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Qualitative Assessment

The PDS qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model. Overall the data are of good quality and should satisfy most users for an accurate bare-earth elevation data product.

Overview

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR point spacing for this project is two meters or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional, elevation mapping technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, PDS employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but the PDS team can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

Analysis

Process

PDS utilizes GeoCue software products as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. PDS uses Microsoft SQL Server as the database of choice.

The PDS qualitative assessment process flow for Clay County, FL and Putnam County, FL incorporated the following reviews:

1. *Statistical Analysis*- A statistical analysis routine was run on the .LAS files upon receipt to verify that the .LAS files met project specifications. This routine checked for the presence of Variable Length Records, verified .LAS classifications, verified header records for min/max x,y,z, and parsed the .LAS point file to confirm that the min/max x,y,z matched the header records. These statistics were run on the all-return point data set as well as the bare-earth point data set for every deliverable tile.
    a. All LAS files contained Variable Length Records with georeferencing information.
    b. All LiDAR points in the LAS files were classified in accordance with project specifications: Class 1 - Unclassified, Class 2 - Ground, Class 7 - Noise, and Class 9 - Water. Class 12-overlap.
    c. Min/max x,y,z values matched the header files.

2. *Spatial Reference Checks*- The .LAS files were imported into the GeoCue processing environment. As part of the URS process workflow the GeoCue import produced a minimum bounding polygon for each data file. This minimum bounding polygon was one of the tools used in conjunction with the statistical analysis to verify spatial reference integrity. No issues were identified with the spatial referencing of this dataset.

3. *Data Void/ Gap Checks*-The imported .LAS files were used to create LiDAR "orthos". The LiDAR orthos were one of the tools used to verify data coverage and point density, to check for data voids or gaps, and to use as reference data during checks for data anomalies and artifacts. This product is not intended to be a project deliverable. The orthos were derived from the Full Point Cloud elevations and LiDAR pulse return intensity values. The intensity values were used as delivered with no normalization applied. Due to the point density of the original collection, the orthos were produced at a 1.2m pixel for the entire area of interest (see Figure 1).

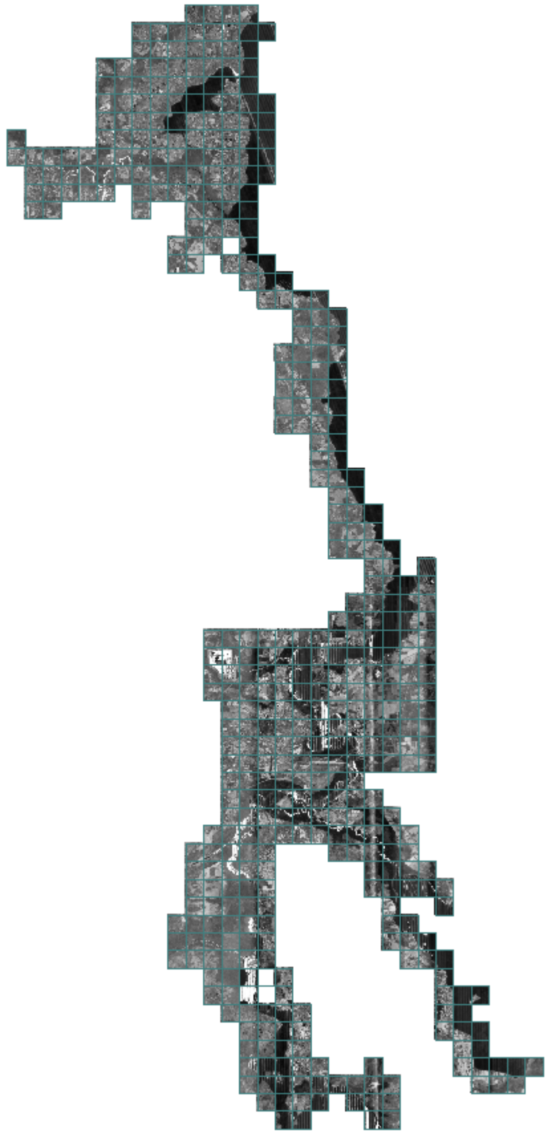

Figure 7 Clay Putnam County LiDAR Orthos produced from Intensity Returns

Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids (Figure 2).

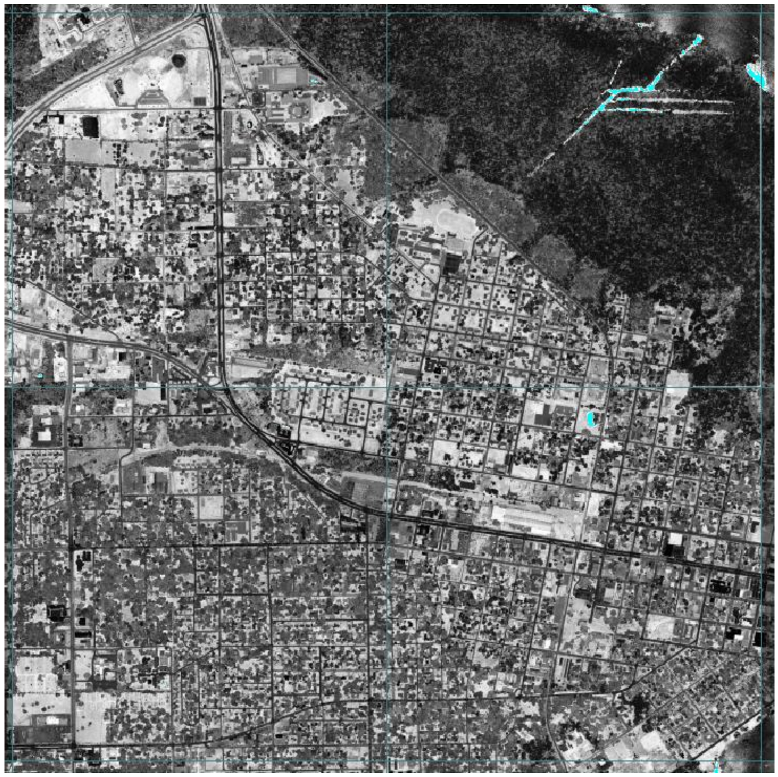

Figure 8 Acceptable voids in data due to water bodies

4. *Initial Data Verification:* PDS performs an initial 10% random check of the data delivery by looking at each tile individually in great detail utilizing TIN surfaces and profiles. If the data set passes the 10 % check, the tiles continue through the remaining QC work flow where every tile is reviewed. If the data set fails the 10% check it is normally due to a systematic process error and the data set is sent back to the vendor for correction. Upon receipt of the corrected tile/s the check is performed again to ensure that any flagged errors were corrected and additional issues were not inadvertently introduced during the corrective action.

5. *Data Density/Elevation checks:* The .LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2(ground points) in the .LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the FDEM project it is stipulated that the maximum post spacing in un-obscured areas should not exceed 1.2m.

   Model statistics were produced and characterized by density, scale, intensity, and elevation. (Figure 5) The low confidence area polygons were overlaid onto the density grids to ensure that all low confidence areas were properly identified with a polygon. As with the LiDAR orthos, this product was produced for Quality Assessment purposes only.

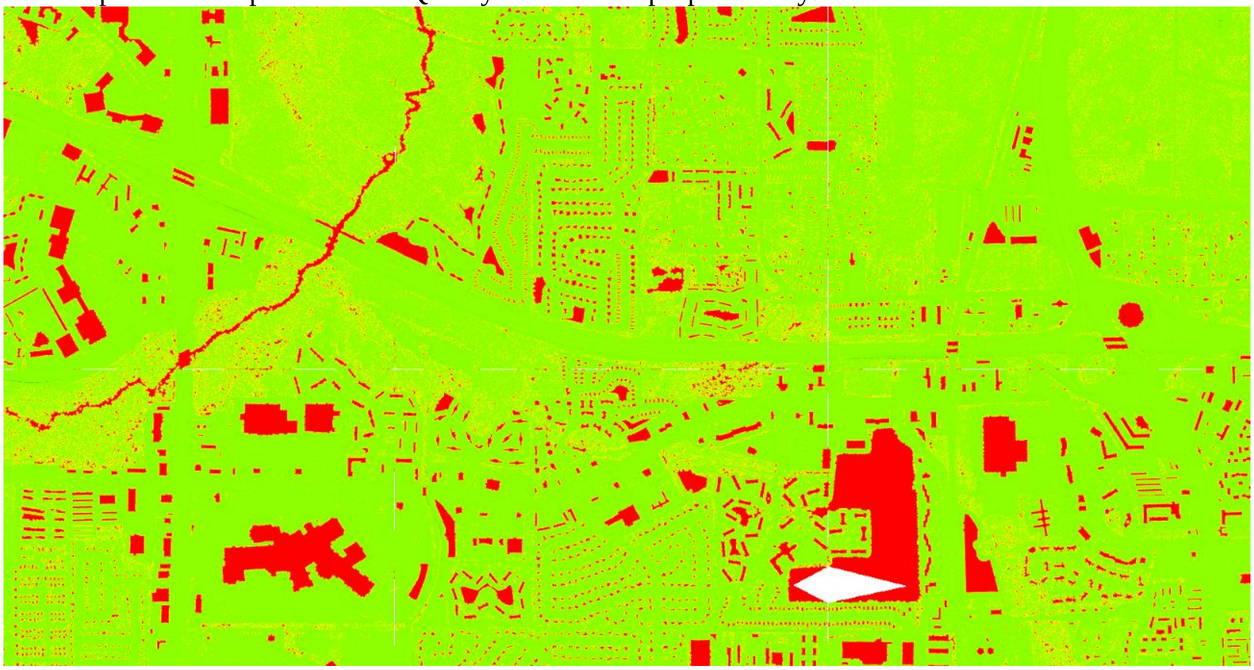

Figure 9 Density grid of Clay PutnamCounties created using a green to red color ramp. Green areas meet project specifications; red delineates areas not meeting minimum density requirements (primarily water, buildings and low-confidence areas)

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6. *Artifact Anomaly Checks.* The final step in the analysis was to review every tile for anomalies that may exist in the bare-earth terrain surface. Items that were checked include, but are not limited to: buildings, bridges, vegetation and water points classified as Class 2 points and elevation "steps" that may occur in the overlap between adjacent flight lines. Any issues found are addressed in the below "General comments and issues".

General comments and issues

The FDEM project area in Clay County FL and Putnam County, FL were reviewed together. The project area did not include the entire counties but consisted of a portion of the Eastern area of both counties. The area is characterized by large water bodies and marsh areas. In the project area there are three urban areas, Palatka, partial area in Middleburg and a partial area in Jacksonville. In the project area there is one national forest, Ocala National forest and one state forests, Welaka State Forest.(Figure 6).

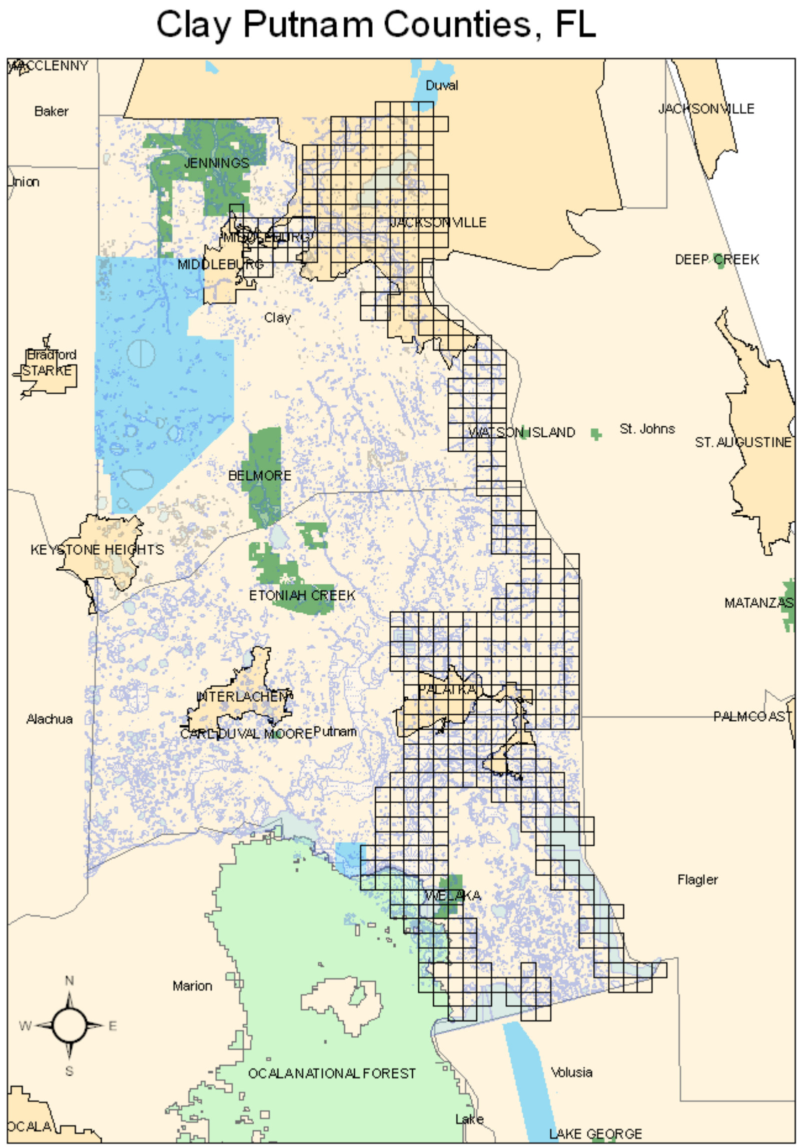

Figure 10 Map of Clay/Putnam Counties Florida with Marsh areas from Florida Geographic Data Library (FGDL)

The initial data acquisition was very dense. Overall the calculated average maximum point density of all the Clay Putnam County LAS files was 1.06 ft or .32m. In general, the bare earth ground surface was clear of artifacts and very clean. The algorithms used to classify the above-ground ground points were very stringent; given the overall physical characteristics of the county this does not seem inappropriate. There is a fine line in the decision-making process of which points to classify as ground. By removing points from the ground classification due to heavy vegetation there is risk of over-smoothing or “flattening” the ground surface which can have a greater impact than leaving points to maintain the ground surface model. In addition, due to the lack of significant elevation changes in the physical terrain there are places where there is no visible break in the terrain between the ground surface and what in traditional mapping would be considered a hard breakline feature, for example roads.

Because the project includes the collection of breaklines, this will be compensated for in the hard breakline collection. The LiDAR data contained sporadic issues such as artifacts or small anomalies which is typical of any LiDAR dataset. Due to the presence of dense vegetation throughout the county, the low confidence area polygons and breaklines are important deliverables for this particular county.

The bare earth terrain model was checked for consistency in bare earth processing, tile edge-match with neighboring tiles, flight line edge match, correct water classification and bridge, building and vegetation removal. There were some issues noted in the qualitative assessment but these were minor and repaired by the contractor. Of the 469 tiles LAS files reviewed the biggest problems were ground points left in the water bodies and on bridge decks. The redelivery of the data was checked thoroughly and passed. The following table and associated screenshots is representative of the issues found in water bodies and of the random gaps explained earlier in this report:

Points		
Tile	**Issue**	**Code**
LID 023847	Ground points on bridge decks	Corrected
LID 039157	Ground points in water bodies	Corrected
LID 022354	Ground points in water bodies	Corrected

LID 023847 – in several areas ground points were found in the .LAS files that should have been removed from bridge overpasses (see Figure 5). This was likely due to an automated filter confusing the points with ground points, based on elevation. These tiles were rejected and subsequently corrected by the mapping vendor.

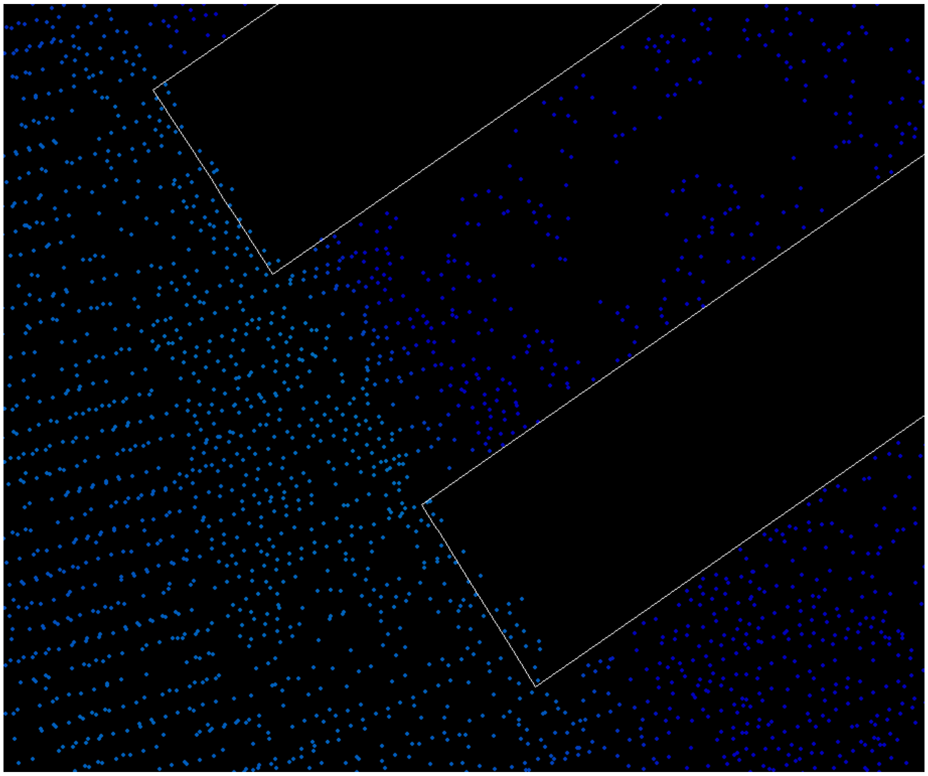

Figure 11 Tile 023847 – example of points classified as Class 2- ground points on a bridge deck.

LID 039157 - example of ground points in water bodies. (Figure 6)

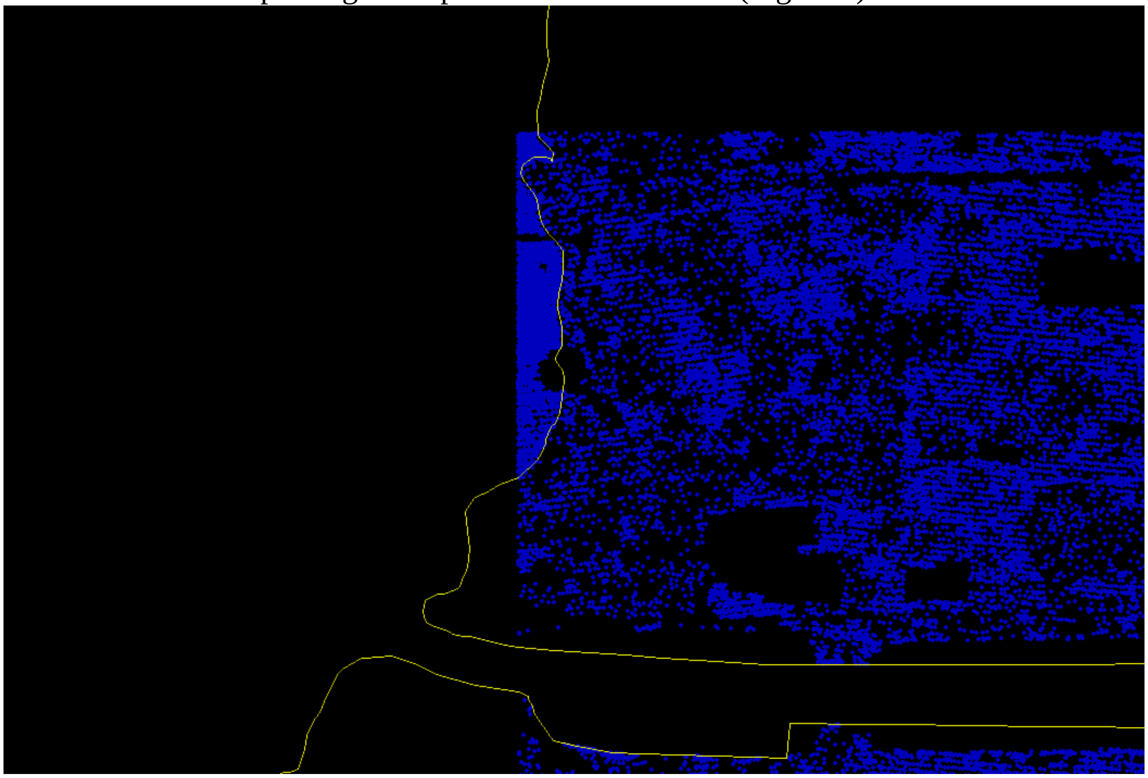

Figure 12 Tile 039157 – ground points not classified correctly in water bodies

LID 022354 – Ground points not classified correctly in water bodies (Figure 7)

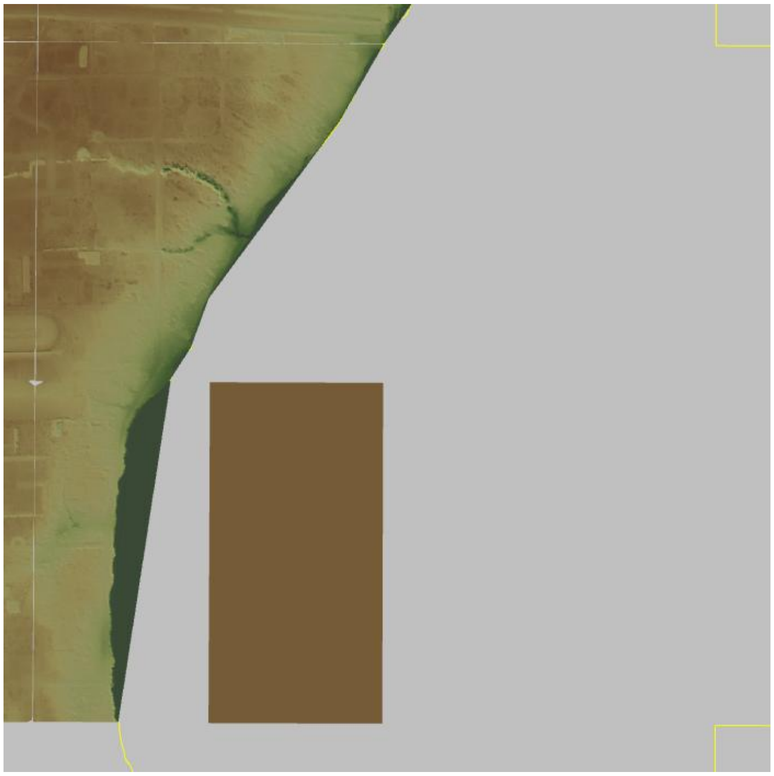

Figure 13 Tile 022354 – Ground points classified incorrectly in water bodies

Conclusion

Overall the data meets the project specifications. The classification of the raw point cloud to bare ground was executed well given the low terrain relief and areas of dense vegetation. The data did fail the initial vertical accuracy assessment and contained areas of improperly classified water points; however these issues were corrected for by the vendor and were not present in the redelivered data.

Appendix H: Breakline/Contour Qualitative Assessment Report

Linear Hydrographic Features

Linear hydrographic features are correctly captured as three-dimensional breaklines – single line features if the average width is 8 feet or less and dual line features if the average width is greater than 8 feet. Each vertex maintains vertical integrity. Figure 2 shows example breaklines and contours of linear hydrographic features.

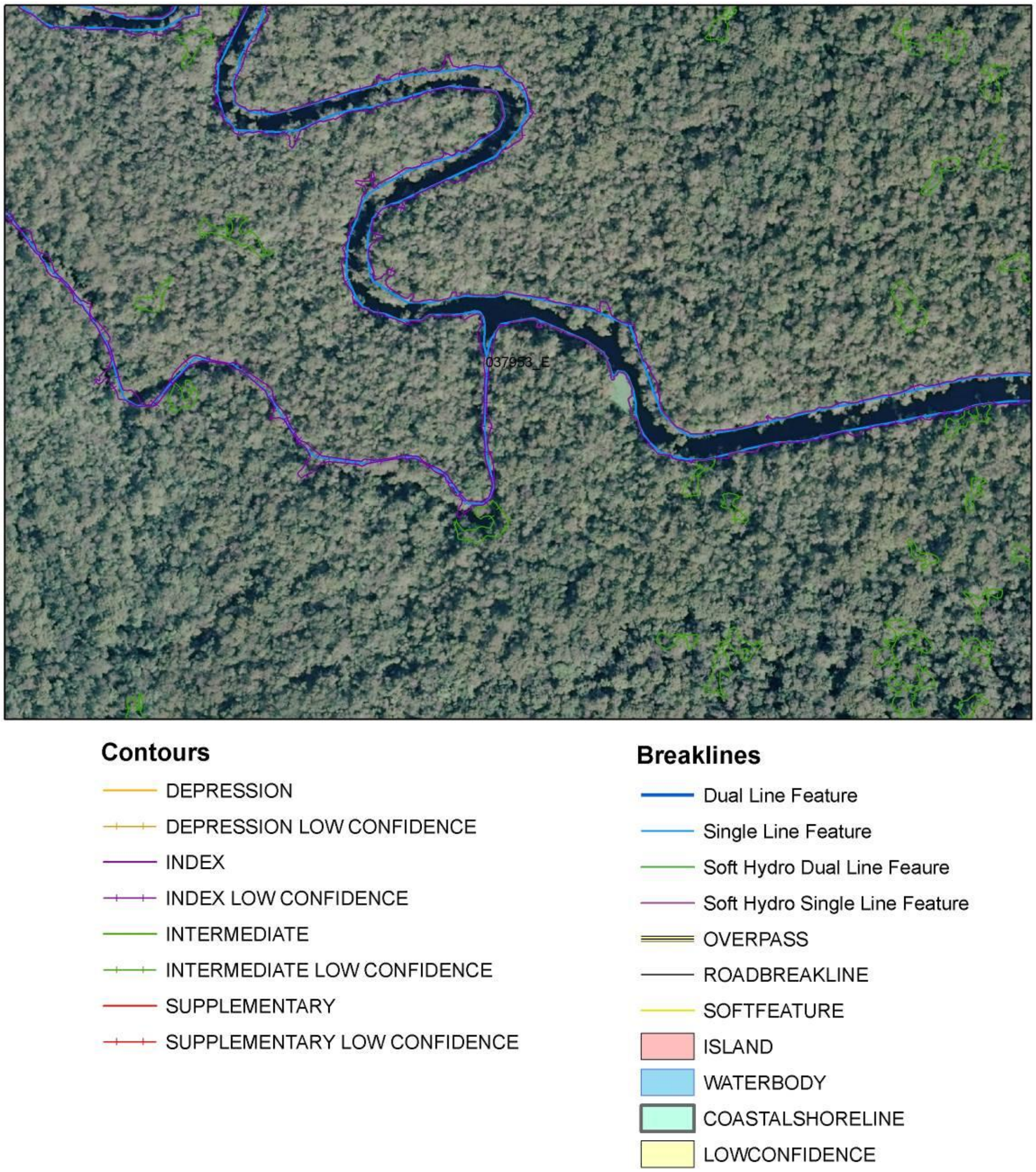

Figure 2. Example linear hydrographic feature breaklines and contours from tile # 37953

Closed Water Body Features

Closed water body features with an area of one-half acre or greater are correctly captured as two-dimensional closed polygons with a constant elevation that reflects the best estimate of the water elevation at the time of data capture. “Donuts” exist where there are islands within a closed water body feature. Figure 3 shows example breaklines and contours of closed water body features.

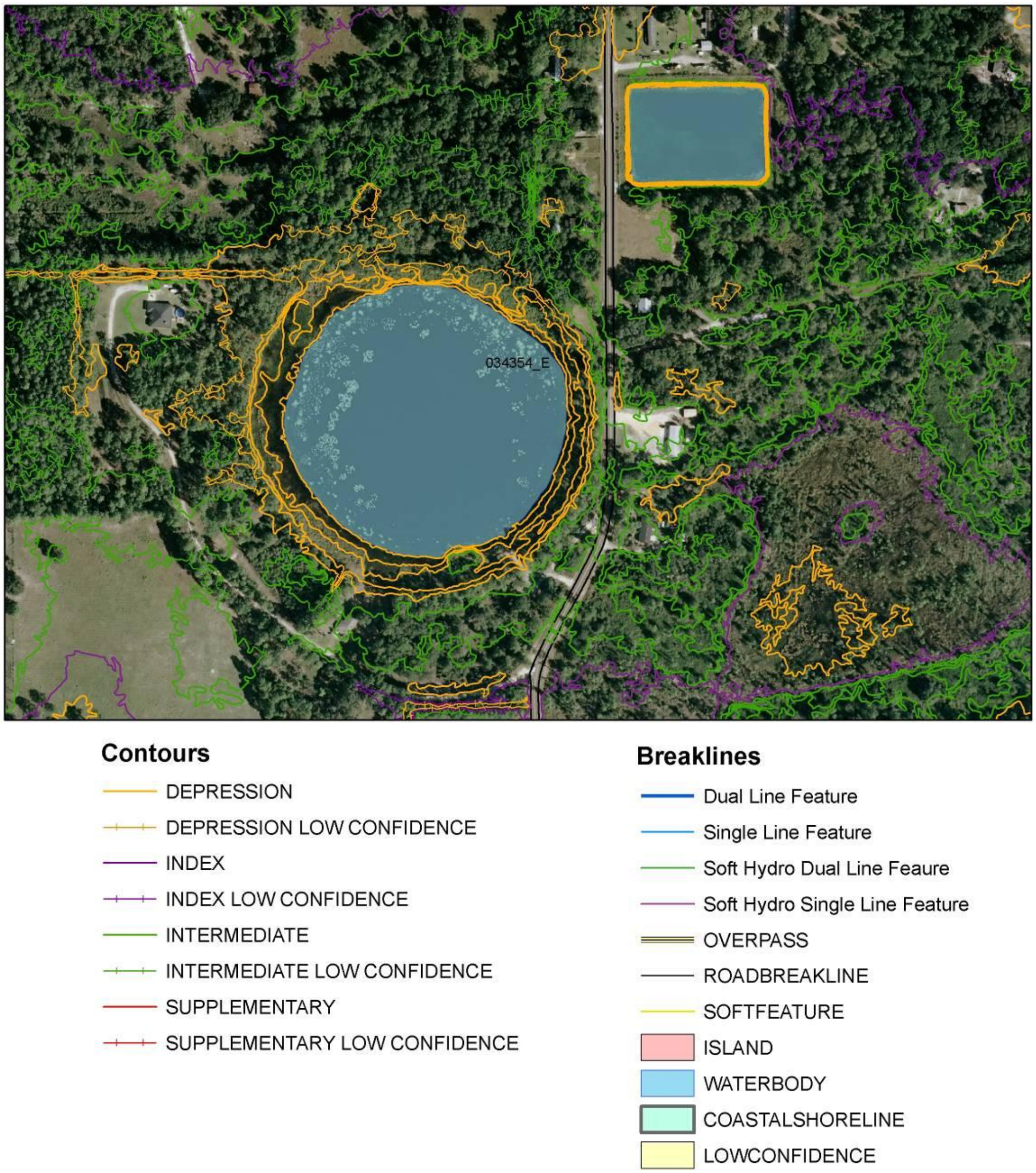

Figure 3. Example closed water body feature breaklines and contours from tile #034354

Road Features

Road edge of pavement features are correctly captured as three-dimensional breaklines on both sides of paved roads. Box culverts are continued as edge of pavement unless a clear guardrail system is in place; in that case, culverts are captured as a bridge or overpass feature. Each vertex maintains vertical integrity. Figure 4 shows example breaklines and contours of road features.

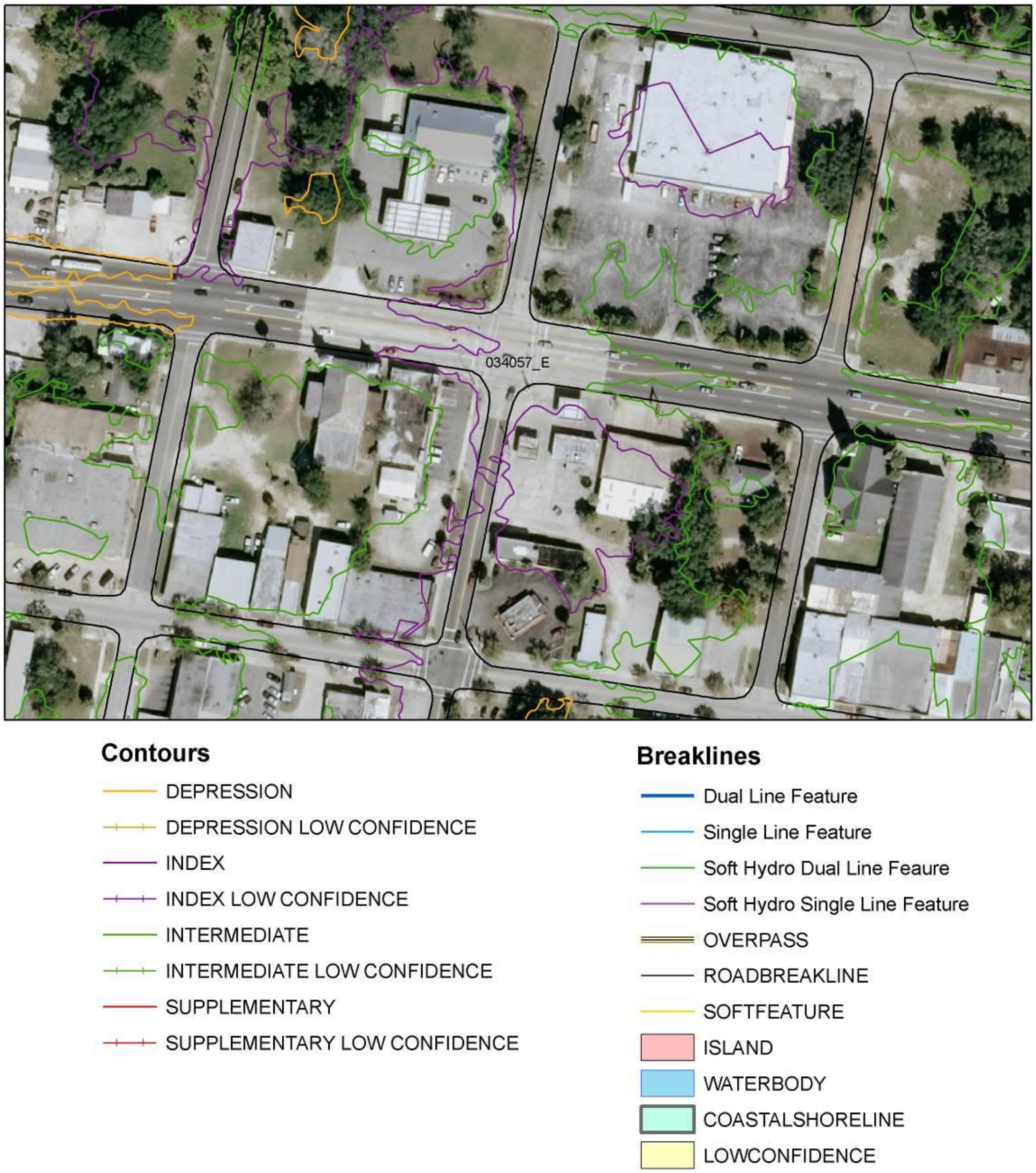

Figure 4. Example road feature breaklines and contours from tiles #034057

Bridge and Overpass Features

Bridges and overpasses are correctly captured as three-dimensional breaklines, capturing the edge of pavement on the bridge, rather than the elevation of guard rails or other bridge surfaces. Each vertex maintains vertical integrity. Figure 5 shows example breaklines and contours of bridge and overpass features.

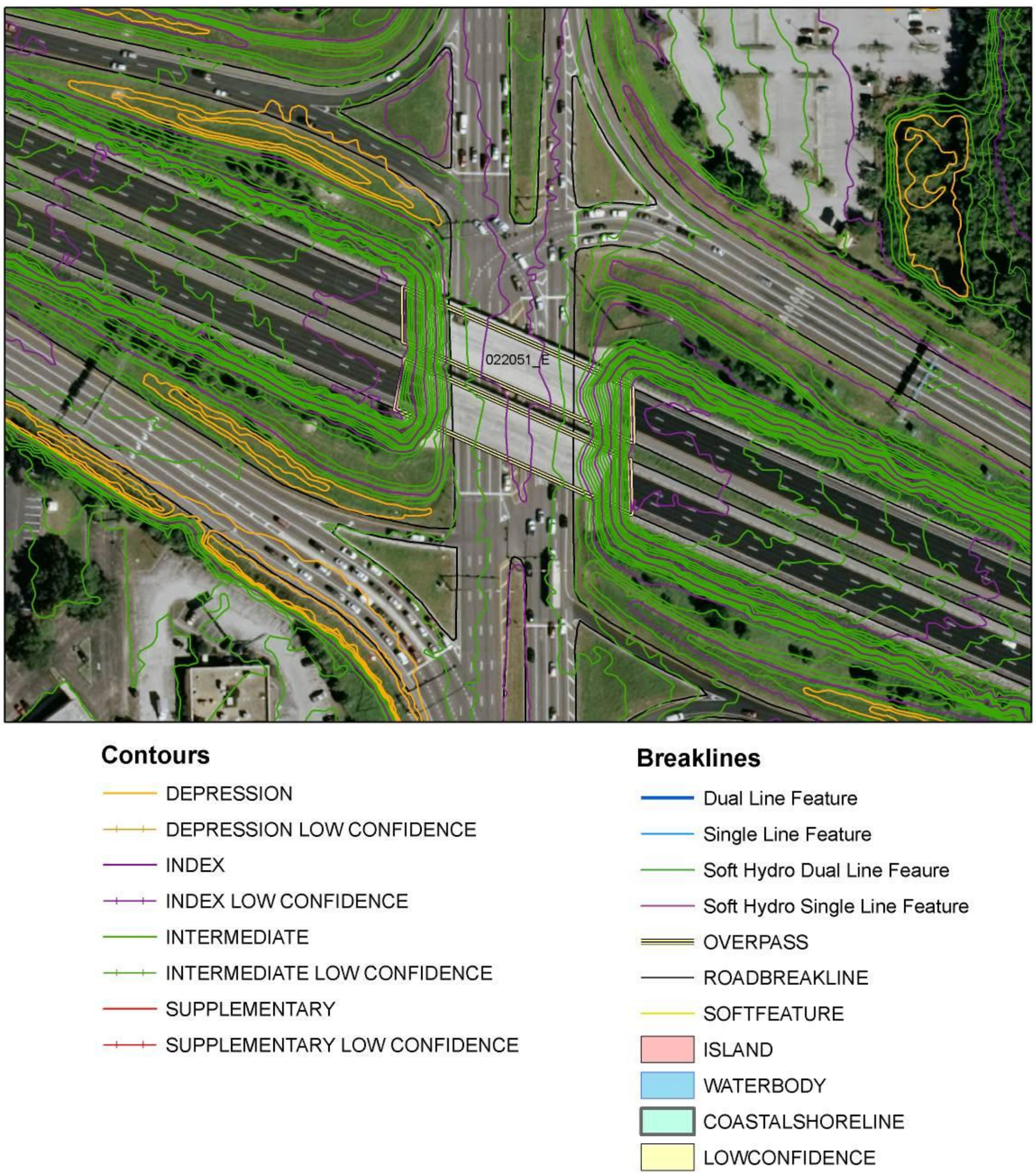

Figure 5. Example bridge and overpass feature breaklines and contours from tile # 22051

Soft Features

Soft features such as ridges, valleys, top of banks, etc. are correctly captured as three-dimensional breaklines so as to support better hydrological modeling of the LiDAR data and contours. Each vertex maintains vertical integrity. Figure 6 shows example breaklines and contours of soft features.

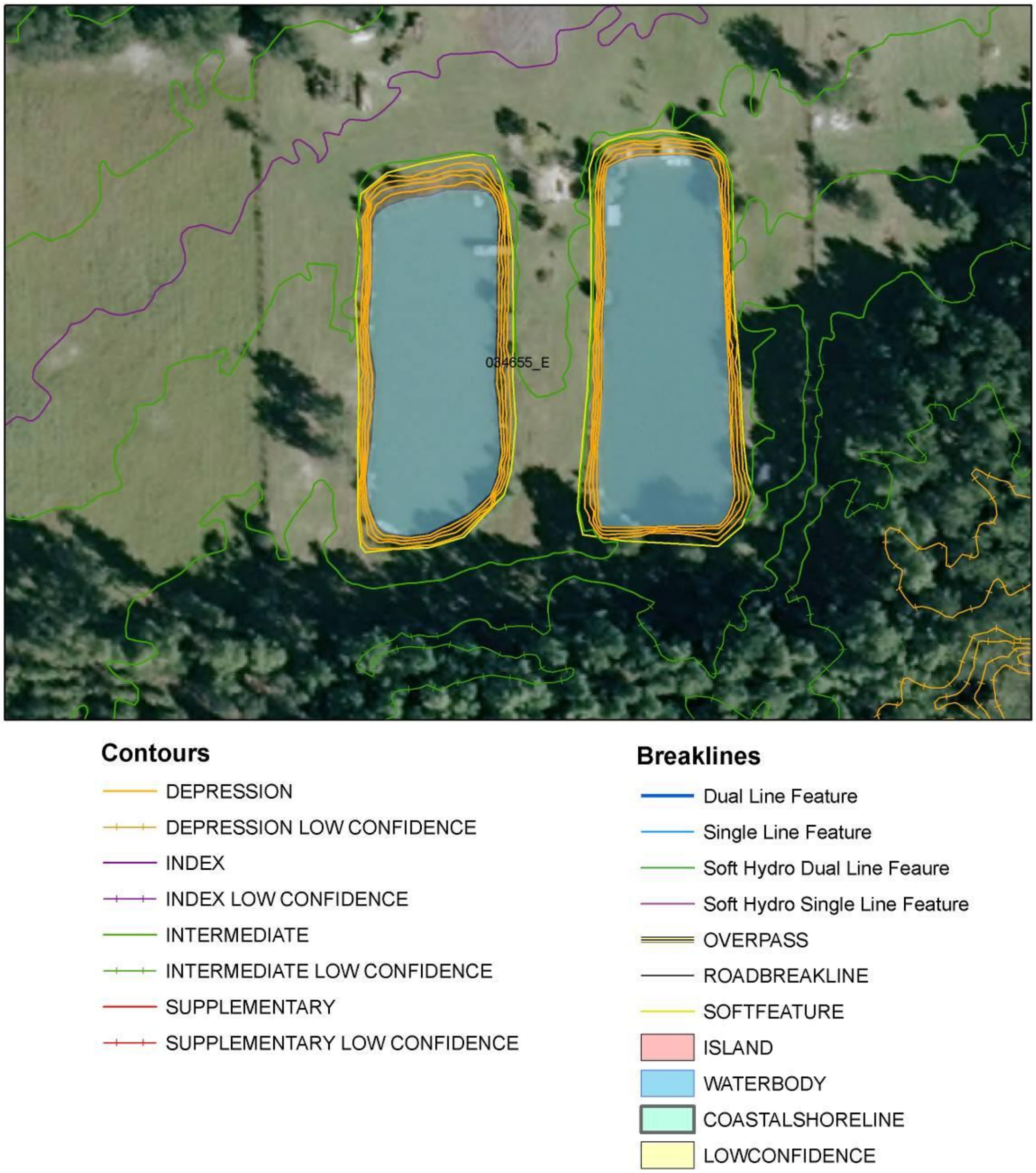

Figure 6. Example soft feature breaklines and contours from tile #34655

Island Features

The shoreline of islands within water bodies are correctly captured as two-dimensional breaklines in coastal and/or tidally influenced areas and as three-dimensional breaklines in non-tidally influenced areas for island features one-half acre in size or greater. All natural and man-made islands are depicted as closed polygons with constant elevation. Figure 7 shows example breaklines and contours for island features.

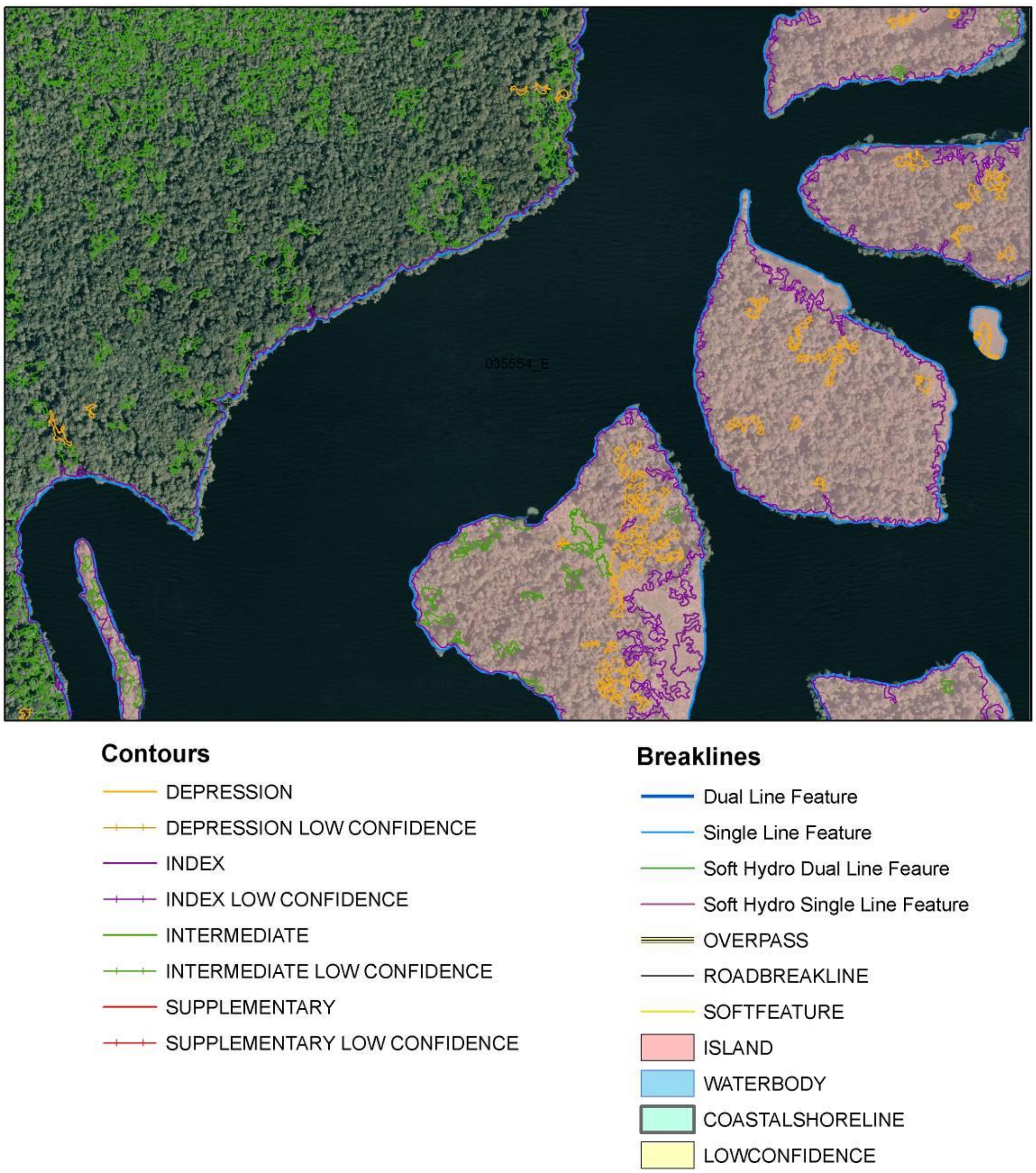

Figure 7. Example island feature breaklines and contours from tile #35554

Low Confidence Areas

The apparent boundary of vegetated areas (1/2 acre or larger) that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM are correctly captured as two-dimensional features with no z-values. Figure 8 shows example breaklines and contours for low confidence areas.

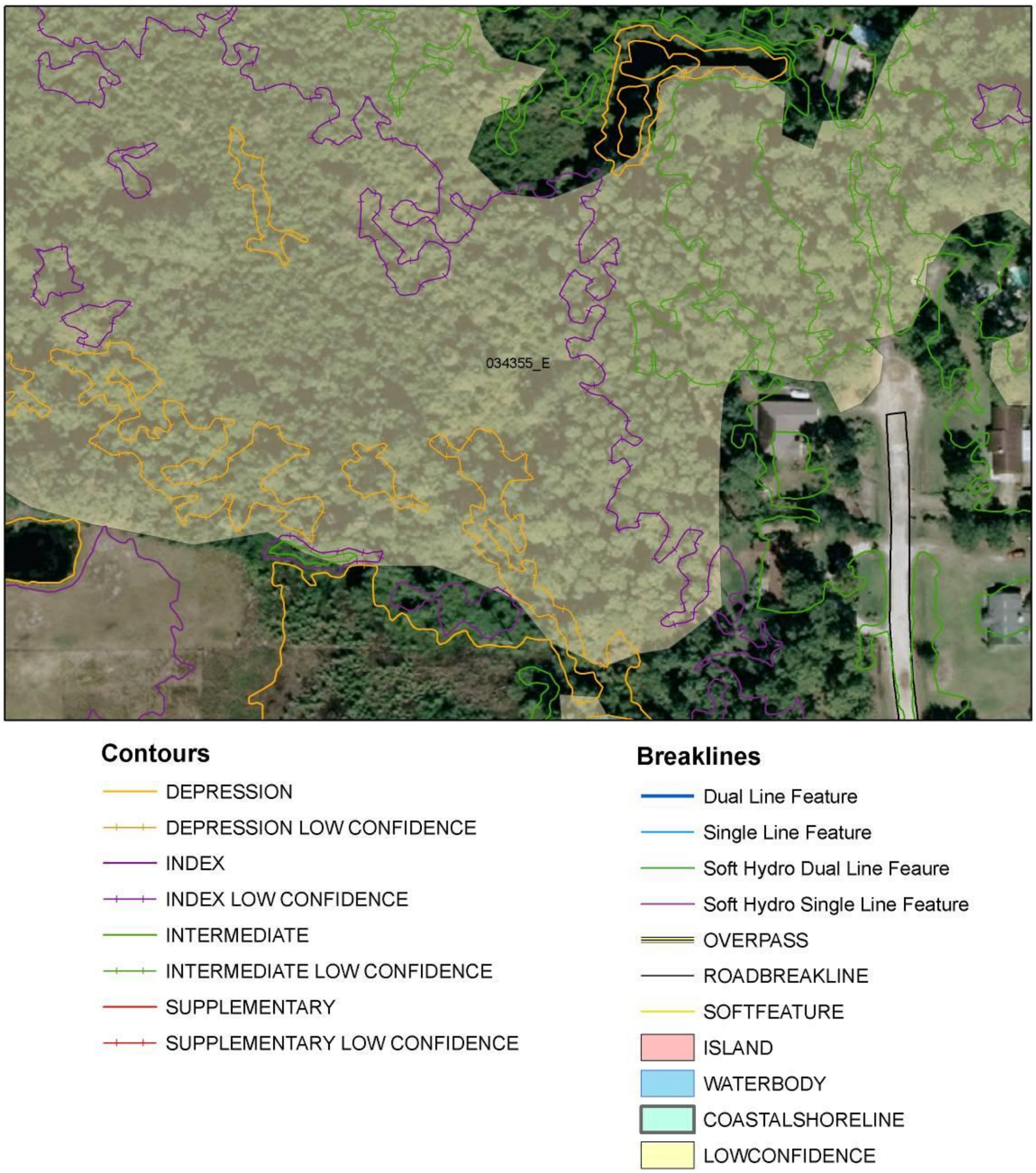

Figure 8. Example low confidence area feature breaklines and contours from tile #34355

Appendix I: Geodatabase Structure